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THE FUNDAMENTALS OF PSYCHOLOGY

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THE FUNDAMENTALS OF PSYCHOLOGY

BY

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PREFACE

This book is intended to fill a gap which exists to-day between the smaller texts and the reference hand-books. I have had in mind the needs of one of my own classes which devotes a year to psychology and includes students who have had no previous work in the subject. They have more than time to cover the present texts but are lost in the details of the larger works, particularly in connection with the nervous system, sensation, and perception.

I have written for the student primarily and have not presupposed any preliminary knowledge. I have particularly avoided reference to current theories before they are explained and have indulged in no arguments on controversial matter for the benefit of colleagues rather than of the student. Opposing theories are discussed only as they may illumine statements of fact or where they have great historical importance and then only if the problem is real but is not settled.

The technical psychologist may miss long discussions of general method and points of view. I have replaced them by fuller statements of the results of experiment and more detailed treatment of the generally accepted body of facts. I have drawn upon the work of all schools without reference to the theories that the workers held, and have stated the results in terms that

seemed most suitable to the particular material. Sensation and perception are discussed in structural terms, action of all sorts in behavioristic terms. This gives some inconsistencies, but they are preferable to the awkward phrases that would result from using the terminology of any school to the exclusion of the others.

My own theory inclines towards a functionalism. The book is more concerned with what consciousness does than with what it is. As opposed to the extreme behaviorism, however, I am not concerned alone with understanding the movements of the organism and the function of the movements, but also with understanding knowledge and the way in which it develops. It is my belief that the content of the science is the same whatever the point of view from which the subject be approached, and that this content is essential and changes slowly and then through growth. The theories are less important and likely to change from decade to decade. In contrast with some of the recent authors I have endeavored to supply the content and, while I have stated my own theories in some detail, have attempted to be sufficiently undogmatic to give the instructor opportunity to develop his own point of view.

I take pleasure in acknowledging the help that has been given in the preparation of the manuscript by Dr. Adams, Miss Perkins, and my wife. All have read the manuscript or portions of it and have made numerous suggestions. The latter has also aided with proofs and index. Dr. Huber has aided much in the selection of illustrations for the neurological portions, and at his suggestion Mr. Atwell of his laboratory has drawn sections for Figures 19, 21, 23, 24, 25, and 26. I express my gratitude to both.

I also desire to thank the individuals and publishers who have permitted me to reproduce cuts: Professor Jennings for cuts from his "Behavior of Lower Organisms," Dr. Barker for illustrations from his "Nervous System," W. B. Saunders & Co. for figures from Howell's "Text-book of Physiology" and Huber's "Histology," to Rebmann Bros. for cuts from Bing's "Regional Diagnosis," and to The Macmillan Co. for cuts from Titchener's "Text-book of Psychology," from Thorndike's "Animal Mind," and Foster's "Physiology."

W. B. PILLSBURY.

ANN ARBOR, MICHIGAN,
April 25, 1916.

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FUNDAMENTALS OF PSYCHOLOGY

CHAPTER I

INTRODUCTION

Just at present there is much dispute among psychologists over the most satisfactory method of defining the science. The difficulty arises in large part from the number of theories held in the past which still haunt the domain of the living science although no longer accepted and, in many cases, entirely out of harmony with the present attitude toward the subject. While the formal definition offers many difficulties, it is comparatively easy to state what the science is doing and the nature of the facts that it studies. It deals with the activities commonly known as mental, the processes of perceiving, of remembering, of thinking, and particularly with the acts of the individual. As in any other science, its aim is first to determine what these activities are, what they do, and then to trace them to their conditions, to understand them in the light of every fact that can have any bearing upon them. It is easier to show what psychology is and what its aims are by concrete illustration than by abstract statements.

Take memory, for example. Psychology is concerned

with knowing all that is possible of how we learn and remember. Every one is familiar with memory in a purely objective way. A lesson is studied and, when occasion arises, much of it can be repeated. How one remembers troubles the ordinary individual very little. When questioned he knows almost as little of how he remembers as does the questioner. The task of psychology is to discover the laws and conditions of learning and recall in all of their details. It must know what methods lead most certainly and quickly to a first learning, what kind of learning will permit retention for the longest time, and how forgetting takes place. These investigations have been carried out in great detail, as will be seen in a later chapter. While memory itself is regarded as a mental process, the measurements of memory are as objective as are measurements of the strength of materials, although of course the variation is greater from measurement to measurement. The experiments require somewhat complicated special apparatus and a special training in manipulation, and the methods used and the results obtained may be stated in terms that make no mention of mind. Thus, the most satisfactory rate for retention, the best method of distributing the repetitions, the rate of forgetting, are determined by objective tests that hold irrespective of theory. It is also possible to study very many of the conditions of recall by objective methods. One may speak a word and ask the observer to speak the first word that occurs to him. A study of these words and of their connections permits a statement in a perfectly objective way of the laws that hold for recall. These are the facts with which psychology must

deal. They may be collected in much the same way for each of the different activities of man.

This purely objective and experimental study of mental activities is observation. It may be carried on for man in exactly the same way as for animals, by making experiments from the outside, with no attempt to discover directly what has been going on within the individual. But this is not the only method of psychology. We may also make use of the individual's report on the processes. He can observe from within what accompanies and precedes the activities objectively measured. This, the process of self-observation or introspection, will in many cases supplement the results of direct observation, and the individual who is experimented upon can often notice occasions for expressions that are not given in the statements themselves. While the fundamental causes of most mental phenomena are as much hidden from him as from the experimenter, he can add an account of accompanying phenomena that is nearly always suggestive, and may at times furnish a solution for the questions raised by the objective results. The two methods of psychology, then, are observation and introspection. One gives the phenomena as they present themselves to the onlooker, the other as they appear to the individual investigated. At present both methods are used under experimental conditions that make it possible to control the stimuli and to provide means of measuring many reactions that would escape either unaided observation or introspection.

While practically all are agreed as to what psychology is to study and on most of the results obtained, there is

and always has been much controversy over what it is that is studied. Three definitions are current at present which differ in the statement of the object to be studied. The first asserts that psychology is the science of mind, a direct translation of the original Greek. Two meanings are given to the word mind. One regards it as something substantial, an actual thing or an actual force which produces certain effects or manifests itself in the phenomena we directly experience; the other, of more recent development, asserts that mind is just these manifestations, the sum of mental states without any assumption as to what it is that produces them. A second definition makes psychology the science of consciousness. Consciousness, like mind in its second definition, is just the series of mental phenomena, the memories, thoughts, perceptions, emotions and feelings as they are immediately experienced. A third definition, most recent of all, defines psychology as the science of behavior. By behavior is meant the activity of the man or animal as it can be observed from the outside, either with or without attempting to determine the mental states by inference from these acts.

The various definitions can be illustrated concretely in the memory process. As theory of mind, psychology regards memory as one of the manifestations of mind and either is concerned with understanding mind through this manifestation or is content to describe remembering as one of the mental capacities. In fact, earlier theories of memory were content to assert that ideas were stored in mind or that they were impressions made upon a waxen plate. In either case, no details could be given

as to how they were stored or how they might be reinstated. Mind was both an active agent and a receptacle, the sole means of accounting for mental states. If mind is to be defined as the sum-total of mental states in accord with the more recent suggestions, it is practically synonymous with consciousness, — the first definition merges into the second. As the science of consciousness, psychology is concerned with a description of the different memory images, with the determination of the order of their appearance and with all else that is related to their structure and function. It takes into consideration nothing that is not to be discovered by the individual who remembers. It excludes consideration of mind as a storehouse, for that is not open to observation; and also of the wax plate and all similar entities. All that it can do is to determine the laws of succession of the mental states, and to describe the mental states themselves. As science of behavior, psychology only need investigate the capacity of the individual to remember. The individual is asked to repeat words or syllables a certain number of times under different conditions. After a certain period or certain periods he is tested to see how many he remembers. From these results laws can be formulated for the most effective means of learning.

The second and third of these definitions are alike in that neither implies any theories concerning what cannot be seen, what is not open to observation. Each would content itself with observation from within or from without of what actually takes place. As in any science, each form of observation may be subjected to experiment, the conditions of learning may be varied at will, the cor-

responding changes in results noted and formulated in laws. The choice between them must be made in terms of the methods that each emphasizes, and on the basis of the accuracy with which each can be made to cover the facts that are to be included under psychology. In strict definition, all is at once consciousness and behavior for most individuals. Few would deny that all behavior, to be known, must become conscious, either to the actor or observer; and none would deny that consciousness, unless it is to remain forever individual, must express itself in behavior. The choice of science of behavior turns, first, upon the fact that consciousness tends to imply something removed from observation, something mystical, a thing, rather than a series of phenomena; secondly, upon the fact that behavior is the more inclusive term; and finally, upon the doubt expressed by recent writers as to whether consciousness exists, at least exists for them individually. It emphasizes the fact that laws of action must first be discovered, and that theories and theoretical explanations must be derived from the actual results of experiment and observation, rather than be accepted in advance.

The real quarrel between definitions lies not as to what the phenomena of consciousness are, nor as to the general laws that express them, but in their theoretical explanation. Thus the exponent of the extreme behaviorist view differs from the extreme subjectivist not in the facts he accepts but in that he does not believe that consciousness exists, or if it exists, that it plays any important part in controlling action. For the subjectivist, on the other hand, consciousness seems the final

term by which all else must be explained; behavior is secondary. In the first definition, the use of mind is very obviously the introduction of a theoretical explanation. No one claims that it is ever open to direct observation, however important it may appear to the individuals that believe in it. These differences of opinion on theoretical points may very well be neglected in the development of a description of the mental life. After facts have been collected and laws formulated, the fundamental problems may be attacked in the light of those results. Laws are bound to suggest wider generalizations, and these in turn fundamental causes or conditions.

Obviously, if we are to define psychology as the science of behavior, we must limit its application, since all of the biological and even the chemical and physical sciences are needed to explain behavior in its completeness. In practice, we limit ourselves to the explanation of intelligent behavior. Roughly, behavior may be regarded as intelligent when it is modified by the earlier experience of the organism. All the acts of certain of the lowest organisms and some of the acts of the highest are to be explained altogether in terms of the physical stimuli and of the constitution of the organism. In consequence, these responses are relatively invariable, — the organism makes the same movements under the same conditions. These do not concern psychology. When behavior is modified, not merely by the physical stimuli and chance chemical conditions of the organism, but also by the results of earlier behavior, we have the first beginnings of intelligence, and the organism offers material for psychology. Even in the highest organisms, psychology

is concerned only with the phases of behavior which cannot be referred directly to chemical and physical changes within and without the organism. It deals in general with the acts of the organism as a whole, rather than of the parts, and it considers the acts which it explains only in so far as they are not explained by physiology and other distinctly biological sciences. In general, again, psychology treats the behavior in so far as it is determined by previous acts of the individual, by the action of more remote influences, while the other sciences treat the same behavior in so far as it is due to the activities of particular organs and to the more mechanical forces.

Psychology in its Relation to Other Sciences. — If part of all behavior is to be explained by other sciences, by physiology, by anatomy and the other biological sciences, the psychologist must take the results of these sciences into consideration. He must know what part of the problem they solve and what they leave over for him to discuss. He must also use many of their results in attaining his own conclusions. Knowledge of the structure and function of the nervous system is particularly important, as in the higher organisms practically all of behavior is an expression of nervous action. Capacity for the more complex forms of behavior develops with the nervous system, and defects in the nervous system are closely correlated with deviations from the normal behavior. Consciousness, too, is closely related to the nervous system. One can become aware of external objects only as stimuli are carried to the brain by the sensory nerves; memory defects accompany injuries

to definite portions of the brain tissue. In fact, we have every reason to believe that all forms of consciousness have definite accompaniments in the nervous system. Viewed from any standpoint, the problems of psychology are closely bound up with the problems of the nervous system. A knowledge of nervous anatomy and physiology is essential to an understanding of either consciousness or behavior. We shall begin our work with a brief survey of the more important facts of neurology. This survey, it may be well to state, is not part of the field of psychology. It is given here only because one cannot presuppose the knowledge on the part of all readers, and the facts are necessary to an understanding of many definitely psychological problems. A full knowledge involves also the results of physics and chemistry. All of the activities of the organism involve chemical processes, and the stimuli to action are physical. In brief, all of the sciences dealing with any of the forces that arouse or modify action and with the nature of the organism itself must be of assistance to psychology.

In addition to the sciences to which psychology must look for aid in solving its problems, it also has close relations with many of the social sciences, which either depend upon it or share with it in the solution of their own problems. Sociology in its attempt to understand society must take into consideration the individuals of which it is composed, and welcomes whatever knowledge psychology can give on the subject. In many of its phases sociology is social psychology. Similarly, much of the work in economics depends upon a knowledge of mental laws. The economist, however, has for the most part developed

his laws of human nature for himself from a study of practical relationships, rather than taken them from psychology. The relationship of psychology to philosophy is, for the theoretical problems, closest of all. Psychology was the latest of the sciences to separate from philosophy, and the attitude toward many of the fundamental problems is still profoundly influenced by philosophical considerations. Each of the definitions of psychology discussed has developed in response to philosophical theories. On the other hand, many of the philosophical discussions presuppose a knowledge of psychology. There has always been an interaction between the two disciplines.

The Varieties of Psychology. — The more usual classifications of psychology have been based upon the ways of approaching the subject, upon the methods used in the investigation, or upon the field that is treated. The older psychologies were divided into rational or deductive, and empirical or inductive (on the basis of the fundamental method employed). Recently all psychology has tended to become empirical or inductive, particularly with the increased use of experiment; and the method of deduction has been applied only to topics that do not lend themselves to experiment or observation. Rational psychology as a separate field has largely disappeared. Even Wolff, who may have been said to have introduced or at least to have made large use of the distinction, was not able to keep the two distinct, but was continually wandering from one to the other. Two branches have received names from the direction of approach: physiological psychology and psycho-

physics. The former treats of the mental processes in their relation to the nervous system and its action. It is implied in all forms of psychology at the present time and differs from the others for the most part only in the relative amount of space devoted to the physiological aspects. All psychologists at present presuppose a knowledge of the nervous system and its action, even if they do not discuss it explicitly. Much the same may be said of psycho-physics. This lays greatest emphasis upon the part the physical stimuli play in mental processes, and the way in which mental states change with changes in physical stimuli. Both physiological psychology and psycho-physics were taken from famous works on psychology, the one by Wundt, the other by Fechner. Closely connected with the physiological psychology is objective psychology, a name given to several recent books. This not merely places the emphasis upon the nervous system and its activity, but also does not take consciousness into consideration at all. It studies behavior altogether from the outside.

Different Fields of Psychology. — Psychology may be divided along the lines of subject matter. Most psychology deals with the adult human individual, but recently many additional and special fields have been developed. Society, or man in the mass, may be studied as well as the individual. A society shows many characteristics different from and added to the qualities of the individual. A mob, *e.g.*, will do many things that few if any of the individuals who compose the mob would countenance in calm moments. These and other phases of group psychology have been studied and a series of important

laws developed. Race psychology deals with the broader mental differences between races and is a natural extension of social psychology but has been less fully developed.

A second group of divisions of psychology, genetic psychology, treats the less developed types, either with the object of throwing light upon the more complex human behavior or for their own sake. The most fully developed of these is animal psychology. The question as to whether animals are intelligent and how their intelligence compares with man's has always interested students, but until within the last two decades most of the conclusions were based upon anecdotes or, at most, upon the chance observations of travellers and naturalists. These were obviously open to suspicion. More recently, experiments upon animals have been carried on both by biologists and psychologists with very important results. The behavior of typical animals from the protozoa to the apes has been studied exhaustively. Much light has been thrown upon their own activities and many points in human psychology have also been illuminated by their results. The development of the individual has also been investigated. Child study has offered a number of conclusions that make easier an understanding of the complicated activities of man. The earliest years and the period of adolescence have received most attention.

Still another important series of problems has arisen in connection with different forms of mental deterioration, the psychology of the abnormal, or pathological psychology. The relation of these studies to normal

psychology has been twofold. They have greatly aided in an understanding of the normal. One is very much more certain that a voluntary act depends upon certain stimuli or sensations when it can be shown that the absence of that stimulus causes a defect in the movement. Disturbances of the self have given a more profound knowledge of what that is or is not than centuries of speculation and introspection. Slighter defects of sensation, color blindness and partial deafness, not to mention the impairment of memory and related processes, have all given valuable aid in the unravelling of psychological problems or have substantiated results obtained in other ways. On the other hand, psychological methods and psychological results have been adapted to the study of the abnormal and defective minds with much theoretical and practical benefit. Certain standardized tests have come into use which make it possible to determine within fairly close limits the degree of intelligence of the individual. These have proved of value in the schools in selecting the children who are unable to profit from the usual training and make it possible to give them special instruction. It has been shown by an examination of criminals and paupers that, in a large number of cases, a mental defect is responsible for their failure to fit into society, and the necessity for special care that shall provide the ounce of prevention has been emphasized. Many of the methods used to-day for the diagnosis of insanity have also been developed in psychological laboratories and much of the treatment has been an outgrowth of psychological principles, an application of psychological methods.

Our Problem. — In this work we shall restrict ourselves to a study of the normal adult human individual. The other branches of psychology will be considered only as their results aid us in understanding this central problem, and this they do at practically every point. We shall use the results of all methods, but shall enter as little as possible into the quarrels as to whether any method is theoretically justifiable. We shall assume that there is a body of fact that is indifferent to the theoretical discussions. Thus, in connection with the controversy now raging whether observation or introspection is *the* method in psychology, we shall remain neutral and make use of the contributions of each. After all, the controversy concerns us only in the form of expression that may be used to state the results rather than in the validity of the results themselves. Most of these results may be expressed indifferently in terms of one theory or the other, and where they cannot we shall use the terminology most suited to the particular statements to be made. The facts are important and will persist, while the theories that interpret them are always in constant flux. We shall be primarily concerned with facts, and the theories will be considered only where they serve to make clear the facts.

CHAPTER II

THE NERVOUS SYSTEM — CORD AND BRAIN STEM

Broadly speaking, the physical basis of mind is to be found in the nervous system. In a very general sense, the nervous system is the organ of mind. When, however, we approach it from the physical side, it is also the organ that makes possible the activities of the body, that permits external stimuli to act upon the muscles and coördinates the different movements so that they may bring about harmonious and unified action. An understanding of the action and even of the structure of the nervous system is very much easier if we keep the emphasis upon the relation of the nervous system to bodily movement, — treat it first for itself, — than if we think of it in its relation to consciousness. The problem of the relation of body and mind may be taken up when we know more of body. The nervous system in vertebrates is made up of the brain and spinal cord with the sensory and motor nerves that extend from these central organs to the sense organs and muscles. The brain fills the upper part of the skull while the spinal cord is found in the spinal column. The details of the structures can be understood more easily if we consider them later in connection with their development in the race and in the individual.

Life Processes in Cells. — In the higher animals it may be said that practically all action is made possible by the intervention of nerve tissue, but this does not hold in the lowest forms. It is much easier to understand the action of higher animals and of the nervous structures themselves if we begin with the organisms that do not possess nerve tissue, that show almost no signs of differentiation. It may be asserted that the type of organism from which all the higher forms have developed is that shown in the single-celled animals, or protozoa. One that is most frequently used to illustrate the type is the amœba. This is an organism composed of a single cell. It is merely a drop of liquid of unknown but highly complex chemical composition contained in a delicate semipermeable membrane. Since it is the original matter from which all tissue is developed, it is known as protoplasm. We know only that protoplasm is made up of highly unstable chemical compounds, mostly hydrocarbons, but the different components have never been completely isolated or analyzed. Whatever the composition of this chemical substance, it is constantly undergoing change. It takes to itself other organic compounds and oxygen and gives off carbonic acid. It is constantly taking something from the medium in which it lives and giving off waste products. Both of these changes take place through the semipermeable membrane by a process that the physicist calls osmosis. Within the protoplasm is a darker spot that is known as the nucleus. This nucleus is closely connected with the nutritive processes and the subdivision of the cell. What the exact and detailed processes are by which all of the changes

take place we do not know, any more than we know exactly the composition of the parts. We do know that some chemical processes must go on within the cell, that the materials involved are admitted to the cell by osmosis

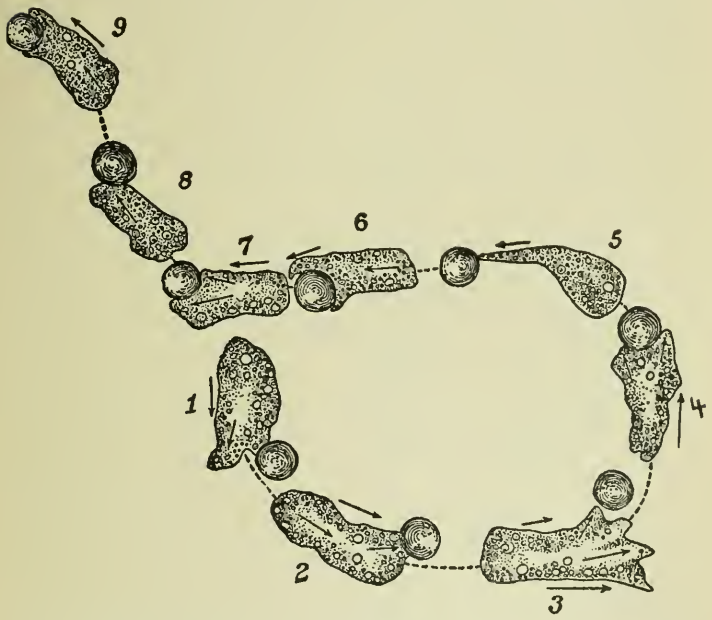

FIG. 1. — Amœba chasing and attempting to ingest an euglena. (From Jennings.)

through the membrane, and that these processes taken together make possible, if they do not constitute, what we call life.

The Activities of Protozoa. — If we study the activities of one of the unicellular organisms, we find that in a simple way it can do almost everything that the most

highly organized animal can, and that it follows the same fundamental laws of behavior. It takes nourishment, it breathes, and, what is most important from our point of view, it moves to find the conditions best suited to its needs. When certain particles come into contact with its membrane, it enfolds them and the process of digestion through the membrane of the cell begins. If other particles come into contact with it, it moves quickly away. When in contact with a solid body, it may send out a prolongation of its body in the form of a foot or what is known as a pseudopod (false foot) which attaches itself to the surface, and the whole body then draws itself up to the foot, which is then again withdrawn into the rest of the body. The single cell is stomach, lung, and organ of locomotion in one.

When one looks at the details of its movements, it approaches more nearly the characteristics of the higher organisms. When stimulated gently by a solid surface, its activity is not changed, but, if the excitation is stronger, it at once stops all movement and rolls up into a ball. If the stimulation is continued, it may send out a pseudopod on the opposite side and roll away from the stimulus. In these two ways the protozoa respond to light, heat, the motion of the liquid medium, the attraction of gravitation, and to the presence of chemicals in the liquid. In general, beneficial stimuli have no effect, while harmful stimuli cause a movement that removes the organism from its neighborhood. Certain organisms, the Stentor that Jennings worked with, *e.g.*, modify their reactions in accordance with the results of the earlier reactions, and thus give the first evidence of learning.

If we use variability of response as marking intelligence, this may be regarded as an intelligent act. The first response of the Stentor when stimulated is to withdraw into its tube. After this has been repeated several times, it changes its form of response to bending to one side to escape the contact. Later it may, when strongly and repeatedly stimulated, loosen its hold on the tube and swim away. These latter responses were called out by permitting water mixed with carmine particles to reach its disk.

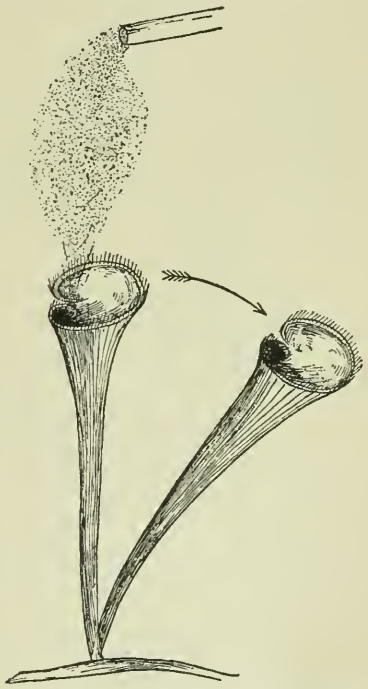

FIG. 2. — Stentor stimulated by carmine particles. (From Jennings.)

Each of these responses is to be thought of as the result of the transfer of a chemical stimulus from the point of stimulation to a more or less remote portion of the cell where the protoplasm or membrane is made to undergo chemical change. The exact nature of the change is not known. Most of the very simple explanations offered have proven themselves inadequate. If the simple reactions are to be explained in terms of the com-

position of the protoplasm and the physical constitution of the environment, it is necessary to recognize that that composition is changed in the Stentor by earlier responses. At the present stage of our knowledge we can do no more than express the belief that a chemical or physical explanation may some day be found. Meantime we may use the action of these simple organisms as a type of the action of cells in general.

Man a Colony of Cells. — These responses are important for us from the fact that one may think of all of the higher organisms as compounded of cells like these simple unicellular organisms, which have undergone various modifications as a result of living together in a colony, but still retain many of the characteristics of the original free-swimming protozoa. For our present purposes, the body of man may be pictured as a mass of cells in which each class has developed peculiarities that fit it to fulfil some one function. With increased capacity for this function, others of the primitive capabilities have been lost. Nevertheless the rudiments of all the capacities of the complex organisms are to be found in the unicellular organisms. In the body, the nerve cells are among the least modified. Unlike the bone cells, *e.g.*, that become so filled with salts as to retain but slight similarity to the original, the nerve cells lack motion alone of the capacities of the prototype. Only certain of the blood corpuscles retain more of the original properties. The leucocytes, or white blood corpuscles, seem to live almost as independent an existence in the blood as the amœba in its watery medium.

Morphology of Neurones. — The cells of the nervous system have retained especially the sensitivity and conductivity of the original organisms. In form, the elements of the nervous system, known as neurones (also spelled neurons), consist of a central cell, the representative of the cell body, and numerous processes

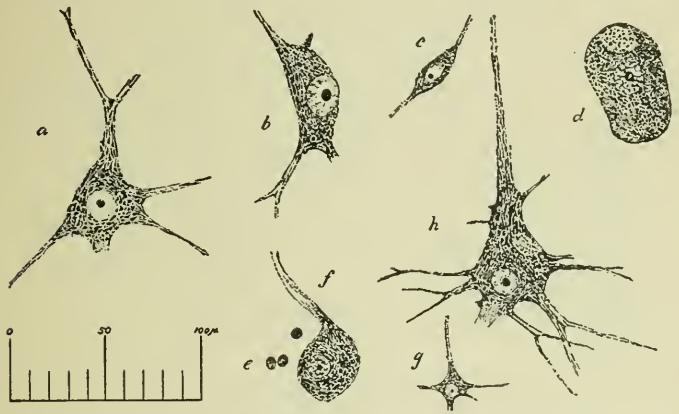

FIG. 3. — A group of human nerve-cells drawn to the same scale. *a*, small cell from the ventral horn of the cord; *b*, cell from Clarke's column; *c*, small nerve-cell from tip of dorsal horn, thoracic cord; *d*, spinal ganglion cell, cervical root; *e*, three granules from cerebellum; *f*, Purkinje cell from cerebellum; *g*, small pyramidal cell from second layer of central gyri of cortex; *h*, giant pyramidal cell from same region. (From Donaldson, after Adolf Meyer.)

that extend in all directions from that cell body. The cell body is of a more or less irregular shape and varies in diameter from about $\frac{1}{200}$ to $\frac{1}{10}$ of a millimetre. The shapes can be best seen from the accompanying diagrams. Within the body of the cell can be made out a nucleus and a nucleolus, as in all cells. Within the body of the protoplasm are small particles that stain

easily, named Nissl or tigroid bodies, the former after their discoverer. In many cells can also be seen fine fibrils that run through the bodies of the cells and into the processes. It is not possible, however, to assert positively what function these different parts of the cell have. The nucleus and Nissl bodies are probably closely connected with the nutrition of the cell. Some theories assign a highly important function to the fibrils, but the balance of opinion seems opposed to regarding any one part of the cell as the fundamental seat of its activity. We cannot as yet analyze the action of the cell into elements, but must think of it as acting as a unit.

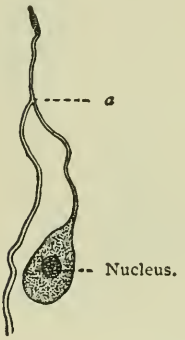

FIG. 4. — "T-shaped" cell from spinal ganglion of frog. (From Boehm-Davidoff-Huber's "Histology."

Axones and Dendrites. — The processes or extensions of the neurones are of two sorts, distinguished rather by function than by structure. One, which serves to conduct impressions away from the cell body, is usually long, with relatively few branches, and these at right angles to the main stem. It is called the axone (also spelled axon). The axone terminates in the end brush, a number of short branches, each of which is probably continuous with a fibril in the axone. The other is usually made up of a number of fibres much shorter and much branched, is in fact usually a thick network like the roots of a tree, an appearance that gives the whole its name, the dendrite. This

usually carries impressions to the cell body. The axones may be of considerable length. A single axone extends

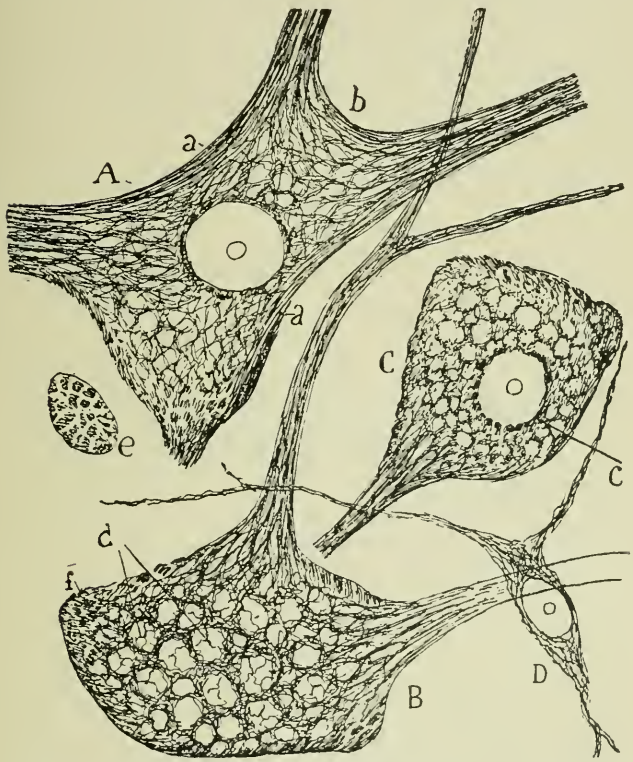

FIG. 5. — Cells from the cord of a rabbit, showing internal structures. *A*, *B*, *C*, motor cells; *D*, small cell from the spinal root; *a*, bundles of neurofibrils; *c*, perinuclear plexus; *d*, the empty areas correspond to the Nissl bodies; *e*, section of a dendrite, showing similarity to cell tissue. (From Cajal.)

from the brain to the lower cord in the case of the motor fibres and sensory axones from the cord to the medulla.

The axones carry impulses away from the cells. The dendrites are nearly always relatively short, less than a millimetre in length. The one striking exception is found in the case of the dendrites of sensory neurones in the posterior roots. These are neurones whose cells are found in the masses of nerve tissue near the cord, known as the spinal ganglia. They serve to transfer impressions from the organs of the skin and lower body to the cord and medulla. The process that runs to the skin may be two feet or more in length, extending from the skin of the toe, for example, to the T-shaped cell body in a spinal ganglion in the lower part of the back. In appearance it is not to be distinguished from the fibre of an axone, but its function is to carry an impulse to the cell, the function of a dendrite. Whether it shall be classed as an axone with the function of a dendrite or a dendrite with the form of an axone is somewhat in dispute among anatomists. We can be content to leave the question of naming open, and look upon it merely as an exception to the general rule.

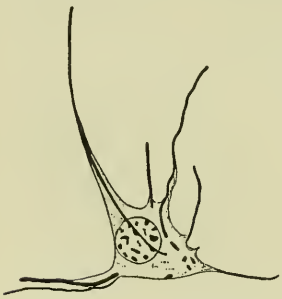

FIG. 6. — Neuroglia cell. In this preparation the cell is prominent. In the more usual method of staining, the fibres are more striking and give the so-called spider cells. (From Huber, after Joseph.)

The Sheaths of the Axones. — The axones do not show a homogeneous cross section, but consist of several parts. In the centre is a core of protoplasm continuous with the structure of the cell body. In it may be

traced the minute fibrils that were mentioned above as found in the cell. About this central core of nervous tissue are found one or two coverings or sheaths. One, the outer, known as the neurilemma, or sheath of Schwann, is a thin white layer, segmented or notched at intervals. Many fibres have within this outer sheath a thicker coating of fatty substance known as the medullary or myelin sheath. This is absent in the nerves of the sympathetic system and at the early stages of the

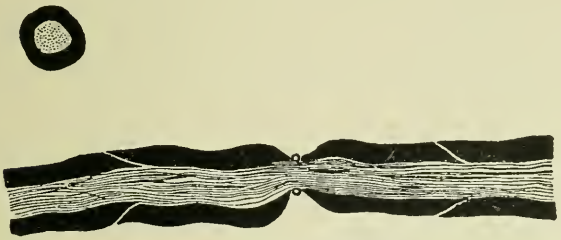

FIG. 7.— Longitudinal and transverse sections of a medullated nerve fibre. The myelin sheath is shown in black; the central protoplasm shows its fibrous structure. (From Barker, after Biedermann.)

development of the fibres in the brain. The neurilemma is found on the peripheral nerves, but is lacking within the central nervous system. The axone is bare, too, for a short distance after it leaves the cell body and the end brush is also always bare. It seems then that the central core alone is essential to the conduction of a nervous impulse. Flechsig has inferred that the medullary sheath is necessary for the action of brain fibres from the fact that this sheath develops successively on different groups of fibres, as the individual grows older before and after birth, and that

fibres continue to be medullated up to and beyond middle age. The facts that some fibres are always without this sheath and that animals can learn before their cerebral fibres are medullated make its importance somewhat doubtful. The central core is bare at the ends of the end brush where it comes in contact with the dendrite of another neurone. The central core, then, may be regarded as the path of the impulse, and the sheaths as largely protective. In a peripheral nerve several thousands of these fibres may be united. In the optic nerve it is estimated that there are 100,000 of them grouped together. Between the nerve cells are numerous cells of a different character, the neuroglia cells. They are supposed to have no part in the conductivity of the nervous system, but are supposed to constitute supporting structures. Their exact function is not known. Their shapes may be seen in Figure 6.

The General Outlines of the Nervous System. — The nervous system of man is merely a conglomeration of these neurones held together by their own cohesion and the pressure of the bones and other surrounding tissues. The peculiarities of appearance of the different structures are due to the way in which the different elements are combined to constitute the masses. As one looks at the nervous system of a mammal, one may distinguish three parts. The largest is the cerebrum, which fills the upper portion of the skull, next below is the brain stem, so called because it may be regarded as supporting the brain proper. The largest part of this is the cerebellum, which lies in man just below the cerebrum, although it is attached to the brain

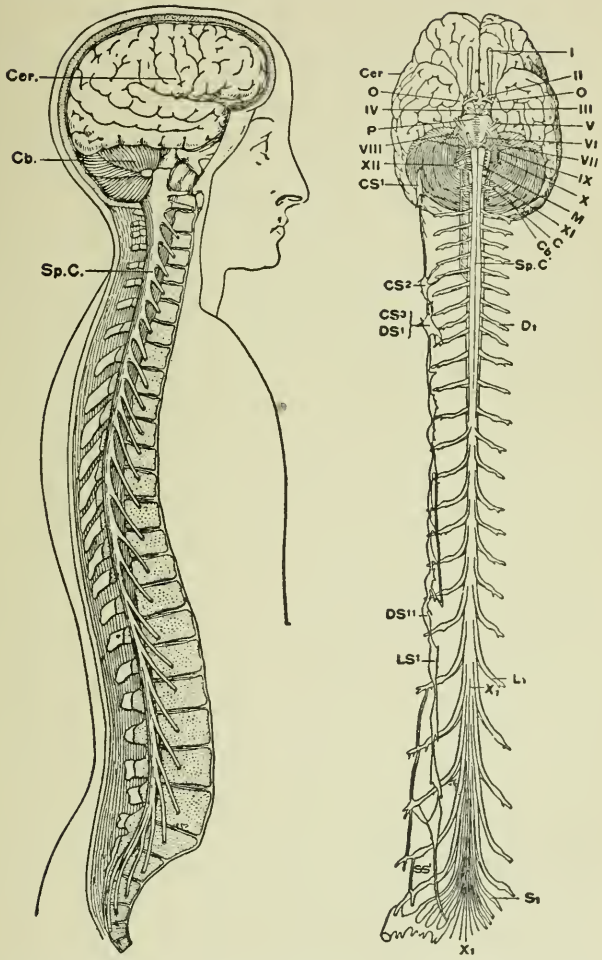

FIG. 8. — The nervous system as a whole. On the left it is seen from the side in position in the body; on the right exposed and seen from the front. *Cer.*, the cerebrum; *Cb.*, the cerebellum; *Sp.C.*, the spinal cord; *P*, the pons; *M*, the medulla. The other letters designate nerve trunks going to the central nervous system and connections with the sympathetic system. (After Bougery.)

stem below several of the other important structures. In the brain stem between the base of the cerebrum and the point of attachment of the cerebellum are the *corpora quadrigemina* and the *thalami*. The latter are at the base of the cerebrum, the former just below it. The lowest and smallest portion of the brain stem is the medulla. Just below that is the spinal cord, the third of our main divisions, which extends about two-thirds the length of the spinal column. The position of these more prominent organs should be carefully studied in Figure 8. Superficially regarded, the most striking differences between different structures are in the colors. The cortex, or outer layer of both cerebrum and cerebellum, is gray; the cord is white. The gray color is given by masses of cell bodies closely crowded together, while the white color is given by the white sheaths of the nerve fibres. Similarly, a section through any part of the central nervous system will show masses of white matter and other masses of gray matter. In the cord the centre is gray, the more peripheral parts white; in the cerebrum the relation is reversed, but in each case the gray matter is a mass of cells, the white a mass of axones. Small masses of cells are known as ganglia.

The structures of the nervous system may also be grouped with reference to function. From this standpoint cells and fibres may be divided into sensory or centripetal, associative or commissural, and motor or centrifugal. The first group are connected with sense organs, directly or indirectly. The axones conduct from the periphery to the centre. The first cells of sensory ganglia are outside of the central nervous sys-

tem, either in the sense organ, or in ganglia near the central nervous system, and their axones connect with other cells nearer the brain. The commissural cells and fibres transfer the impression from sensory cells to motor cells. The motor or centrifugal neurones stand in immediate connection with the muscles, or with neurones which serve to innervate the muscles, — are members of the chain that conducts impulses from the centres outward. The neurones that possess these different functions cannot be distinguished structurally. One can make no general statement as to what characterizes sensory, motor, or commissural neurones. The functions depend rather upon the connections in which the neurones are found than upon their structures.

Development of Embryo. — To understand the structural relations, one must go back to the development of the nervous system in connection with the embryology of the organism as a whole. Many relations, very complicated in the developed organism, are very simple in the earlier stages. The complexities are caused by the conditions of growth. Our sketch of the development must be very brief, with many omissions, but even this may be helpful at some points. The complete adult is developed from an original cell, the fertilized ovum, by a process of subdivision. The original cell divides into two, each of these into two, and so on. At first the derived cells are exactly like the original so far as can be made out. They are grouped compactly. The first sign of differentiation comes when a hollow appears within the mass, and the enclosing cells divide into two layers, an outer, the ectoderm, and an

inner, the entoderm. Soon a third intermediate layer develops from the others to constitute the mesoderm. These layers may be distinguished throughout the remaining development and give rise to different parts of

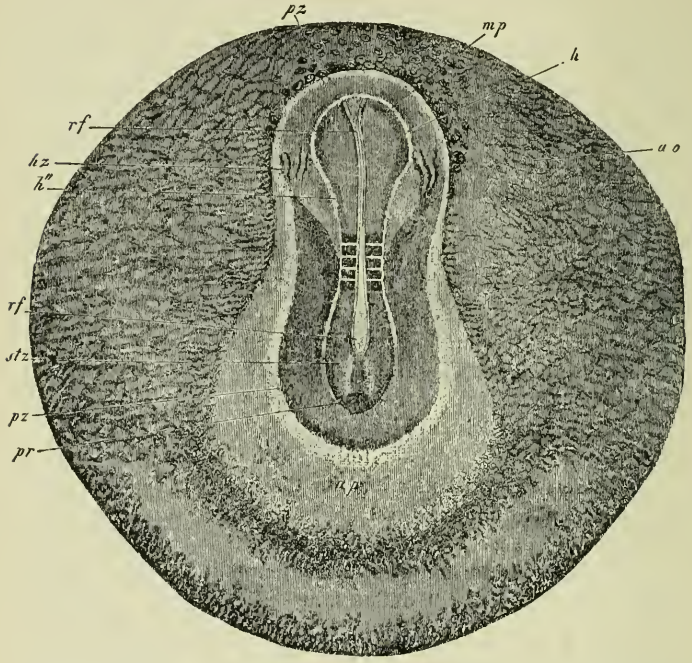

FIG. 9. — Embryo of a rabbit at eight days to show the neural groove. *rf* is the neural groove; *h*, the region in which the fore-brain is to develop. (From Kölliker.)

the organism. The entoderm gives rise to the inner wall of the internal organs, and to certain organs, as the liver and pancreas. From the mesoderm develop the supporting structures, connective tissue, bone,

muscle, and the body of most of the internal organs. The outer layer and its appendages develop into the skin, the mucous membrane of the mouth and nose, and, what concerns us most, into the nervous system and the essential parts of the sense organs.

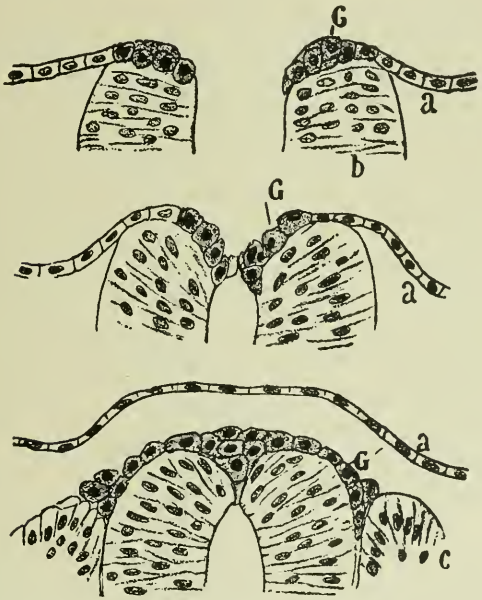

FIG. 10. — Closing of the neural groove. The figure at the top shows the groove still open; in the next, the sides approximate each other; in the lowest, the closure is complete. *G*, the cells from which the spinal ganglia develop; *a*, the ectoderm; *b*, the epithelial lining of the medullary tube.

The Development of the Nervous System. — It is interesting to note how the outer layer of the embryo gives rise to the nervous system which finally becomes embedded so deeply in the structure of the body. Very

early in the embryonic life, within the first two weeks, there appears upon the surface of the embryo a slight depression known as the neural groove (Fig. 9). This gradually grows deeper, and finally the upper edges grow together and form the neural tube (Fig. 10). From the walls of this tube the entire nervous system grows. The forward end becomes the brain, the other longer portion, the spinal cord. The cells that line the tube give off first masses of cells with radiating fibres that serve as a supporting structure or scaffold (Fig. 11). Some at least of these develop later into neuroglia cells, the supporting tissue of the central nervous system. This first supporting structure takes the general form and may be said to prepare the way for the truly nervous structure. After the supporting or ependymal

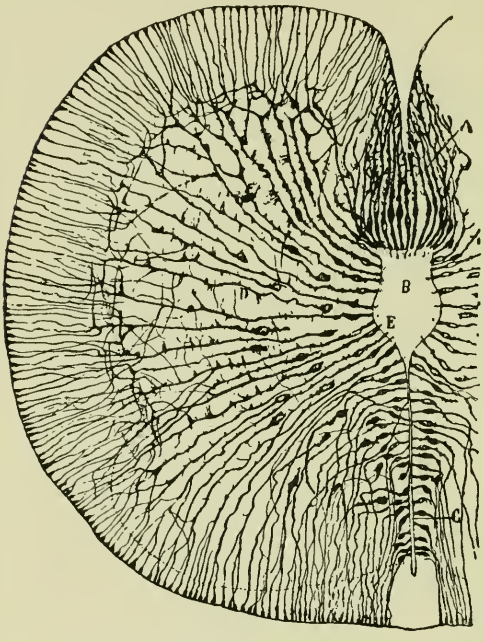

FIG. 11. — The ependymal or supporting structure of the embryo cord. (From Cajal.)

structure is well developed, further division of the cells lining the tube gives rise to embryo neurones or neuroblasts. These make their way outward toward the position they are to occupy in the adult cord. As the neuroblasts develop they send out processes, axones and dendrites. surround the mass of

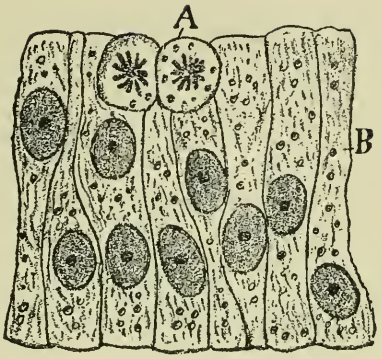

FIG. 12. — Epithelial cells lining the neural tube and germinal cells, *A*, that have developed from them. (From Cajal, after His.)

The axones grow outward and neuroblasts. A section of the cord at the end of the first month shows a layer of epithelial cells about the central tube, farther out the neuroblasts and then the axones (Fig. 13). Everywhere in the brain as well as here in the cord the principle holds that the processes are outgrowths of the cell bodies. The axones spread from the cells up the cord to the

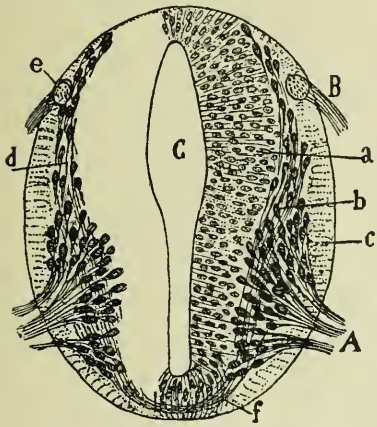

FIG. 13. — Schematic section of embryo cord. *A*, anterior or motor root; *B*, posterior root; *C*, central canal; *a*, epithelial wall; *b*, neuroblasts or embryo neurons; *c*, the primordial white matter. (Cajal, after His.)

higher centres, and on the ventral side in particular outward to the muscles, even to the remote parts of the body. Meanwhile the sensory neurones are developing in the

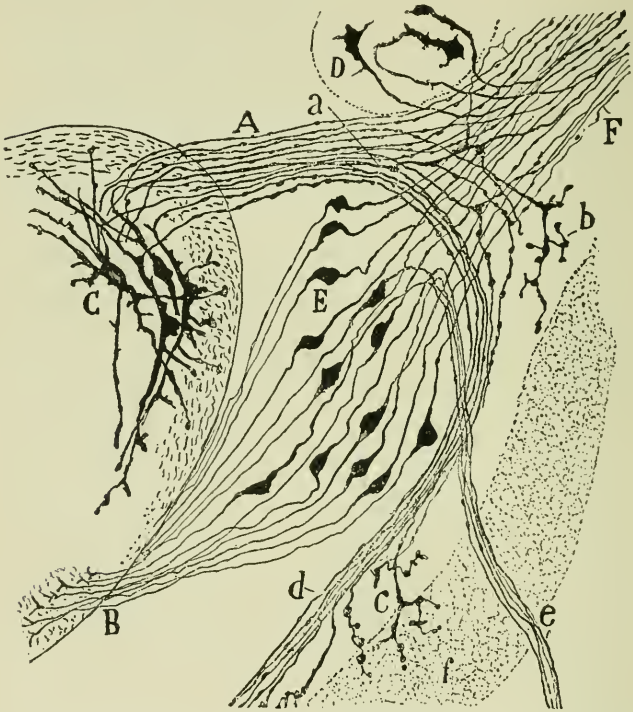

FIG. 14.—Development of dorsal root ganglion with cord. *A*, motor nerve; *B*, posterior root, fibres from ganglion entering cord; *E*, 'T'-shaped cells of dorsal ganglion in their bipolar stage; *e*, sensory nerve, dendrites of 'T'-shaped cells. (From Cajal.)

dorsal ganglia. When the walls of the neural groove grow together to form the tube, portions of the ectoderm are cut off both from the tube and from the sur-

face. They move away from the median plane, and are surrounded by mesoderm tissue. The original ectoderm cells give rise to neurones. At first the processes of the neurones grow out from either end; one goes outward to the end organ in skin and muscle, the other grows into the cord and sends fibres upward in the dorsal white columns or into the central gray. Later in the development, the two processes grow together for a short distance from the cell and then grow off at right angles to the original stem. They thus resemble a 'T,' and the cells are known as the 'T'-shaped cells. Before birth the germinal layer stops giving rise to new cells and forms a single layer of cells lining the central tube.

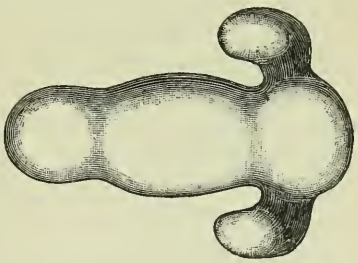

FIG. 15.— Development of brain vesicles seen from above. The hemispheres may be seen growing from sides of fore-brain. (From His.)

The Development of the Anterior Portion of the Neural Tube. — The growth of the forward end of the neural tube, the part from which the brain develops, follows much the same plan. The supporting structure and the neuroblasts appear as in the cord. One difference should be emphasized, however, that the neuroblasts are projected farther from the tube and the axones grow inward and extend up or down within the masses of cells. In consequence the white matter is, for the most part, within; the gray, on the surface. One other problem upon which development throws

considerable light is in the longitudinal arrangement of the parts. By the end of the second week, the forward end of the tube bends sharply downward, ventrally, and becomes divided into separate pouches or vesicles. At first three, later five, vesicles are to be seen. These are marked by constrictions in the tube

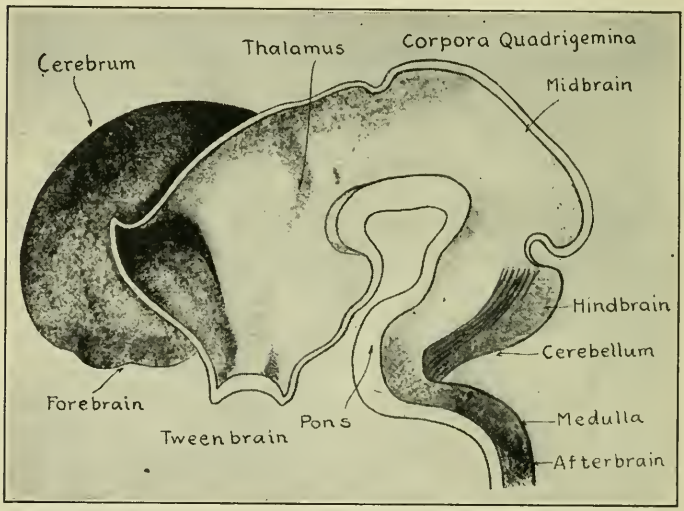

FIG. 16. — The five-vesicle stage of the human brain, giving names of vesicles: fore-brain, tween-brain, etc., and the parts of the adult brain that develop from each. (After His.)

at four places. Two most marked are just before and just behind the bend in the tube. The vesicle between is the mid-brain. The region in front is divided by a shallower groove into end-brain or fore-brain, and tween-brain, while the portion just behind is similarly divided into the hind-brain and after-brain. These early divisions give the name to the corresponding parts of the

adult nervous system. The cerebrum develops from the forebrain, the thalamus and other parts from the tween-brain, the corpora quadrigemina and other structures from the mid-brain, the cerebellum and pons from the hind-brain, and the medulla from the after-brain. In each the walls are very much thickened and at many points there are very large outgrowths, but all grow from the lining of the original tube by the process of cell division indicated above. The original cavity undergoes changes of shape in many places. It becomes much heightened in the hind-brain to constitute the fourth ventricle, in the mid-brain it retains its original shape, and continues small as the aqueduct of Sylvius. It broadens in the tween-brain to the third ventricle and assumes a complicated bifurcated form in the cerebral hemispheres, the lateral or first and second ventricles. Nevertheless it remains continuous throughout from the lateral ventricles in front to the bottom of the spinal cord. It is filled everywhere with the cerebrospinal fluid.

One peculiarity deserves special mention, — the development of the cerebral hemispheres. They appear early as lateral swellings on the end-brain. These grow first to the side, then upward and back until they cover mid-brain and cerebellum, an outgrowth of the original hind-brain. The two hemispheres are distinct from the beginning. They merely come into contact along the median fissure; there is no organic connection between them except at the base. In this growth backward, the cerebral hemispheres are folded here and there, and these folds account for some of the perma-

nent markings upon its surface. Most striking of these is the fissure of Sylvius. This can be seen from the second month. It develops in very much the same way as the median fissure from the growing together of one outgrowth of the frontal portion and the lateral portion of the more posterior portion. When these grow together on the surface, they leave considerable portions

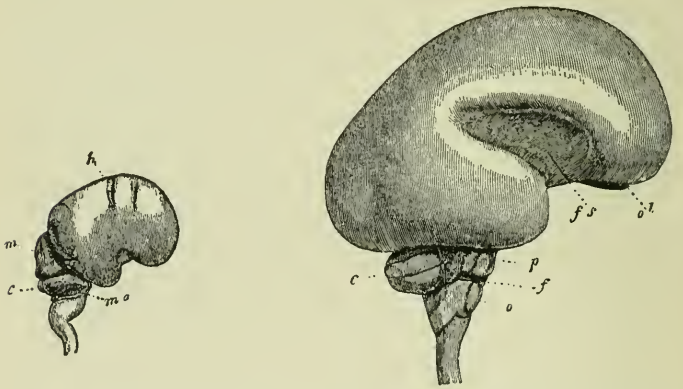

FIG. 17. — Shows development of the hemisphere, the left figure at three months, the right at six months. *fs* is the fissure of Sylvius; *c*, the cerebellum; *m*, the mid-brain. (From Kölliker.)

of their superficial areas in juxtaposition well below the surface. The walls of this deep fissure constitute the island of Reil.

In the course of the development, then, we find neurones originating from the cells that lined the central tube. In the neighborhood of the tube, masses of nerve cells arise, now in a continuous structure as in the cord, now with exuberant growth in comparatively isolated regions separated from other cell masses by

regions of white matter, as in the cerebrum and cerebellum. From these cells the axones grow out for long distances to the sense organs and to the muscles on the peripheral side and to the other cell masses in central structures, until sense organ is connected with muscle, and centre with centre throughout the organism. The problem of understanding the nervous system is very largely one of tracing these connecting paths from sense organ to centre, and from centre to centre within the entire system.

The Nature of the Nerve Impulse. — The function of a nerve unit or neurone is to conduct from sense organ to muscle. The question naturally arises, what is conducted? The answer to this is not fully determined. In fact, theories vary from decade to decade. An indication that will at least limit the possibilities is obtained from the rate of propagation. This has been determined to be from 100 to perhaps 230 metres per second. That at once removes the possibility that the process is a simple electrical one. One other fact in connection with the determination of the character of the nervous impulse is the extremely small evidence of fatigue and the small amount of nutriment required by the axone in its propagation. Nerves have been stimulated for four or five hours and at the end of that time have been just as ready to respond as at the beginning. It has also been found impossible to discover any heat as a result of their action, and the amount of carbon dioxide given off is extremely slight. These statements hold only for the conducting nerve fibre, not for the cell. Evidently, then, the energy changes involved

in conduction are relatively slight. Still another fact that must be taken into consideration by any final theory is the electric current (current of action) that is produced whenever the nerve is stimulated. If the cut end of a nerve is connected with its sheath through a delicate galvanometer, it is found that an electric current flows from the cut end to the sheath.

Two theories that may be regarded as rivals at present have been suggested as to the nature of the current. One is that the impulse is conducted by chemical changes within the nervous tissue, somewhat as the spark is conducted along a fuse. Against this assumption must be put the quickness with which the nerve recovers from fatigue, and the slight evidence of chemical changes, heat, etc. On this theory the current of action would correspond to the current that is developed by the chemical action in a battery. The other theory, also in favor at the present, makes the nerve a type of ' core conductor ' in which the central nerve tissue and the sheath constitute core and sheath. The impulse corresponds to the movement of a charge of negative electricity along the fibre. A model consisting of a core of platinum and a sheath of sodium chlorid solution shows phenomena similar in many respects to the action of the nerve. The current of action, rate of conduction, and other characteristics of the nervous action can be reproduced. Each theory leaves much to be desired in the explanation of the details of nervous action. All that can be said is that the conduction is due to relatively slow progressive changes within the nerve core, and that these changes

are of chemical or electro-chemical origin. Whatever the character of this nervous impulse, it constitutes the essential activity of the neurone, and as it travels from sense organ to centre or from centre to muscle, the processes of sensation or of movement are made possible.

The Course of the Impulse. — The specific activities of the nervous system depend upon the course that the impulse takes through it. The simplest form of nervous response that an organism makes is called the reflex. It is the type of all nervous action. The winking of the eye, the withdrawal of the hand when burned, are primarily reflexes. The explanation of the reflex is to be found in the presence of a continuous connection of nerve tissue, of chains of neurones, between the sense organ excited and the muscle. The simplest reflex involves at least two groups of neurones, a sensory and a motor. It can be seen most clearly in the spinal cord. If a finger be pricked, an impulse passes to the cell body of the spinal ganglion, thence to the motor cell; its activity causes the muscles of the arm to contract and draw back the hand. That these reflexes depend upon the nervous connections in the cord and upon these alone is evident from the fact that they persist in the lower animal after the cord has been cut off from the brain, but cease if the cord is destroyed or the nerves that lead to or away from it be severed. In a frog, whose head has been removed or whose cord has been cut in its upper part, the reflexes persist. Stimulation of the skin causes movements of the members. Even a dog may be kept alive after its brain has been removed, and this 'spinal dog,' as it is called, carries

on the reflex activities of the lower body in a perfectly normal way. When stimulated on the skin of one foot, that foot will be drawn back. If the intensity of the stimulation be increased, the opposite member is moved, and as the stimulation is still further increased in intensity, movements up and down the trunk at many different levels will be made. In the frog, for example, if a bit of paper be dipped in acid and put upon the skin of the right thigh, the first effect is to bring the right foot up in an attempt to wipe away the paper; if that foot be held, the other will be brought across and remove the stimulation.

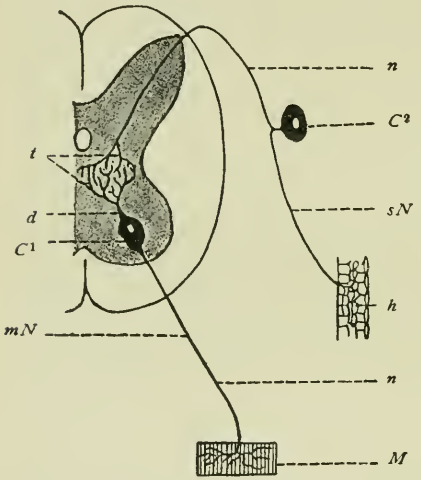

FIG. 18. — Simple reflex connection in the cord. C^2, 'T'-shaped cell in the posterior root ganglion; *sN*, sensory neurone; *h*, dendrite or telodendrion of sense organ in skin; C^1, motor cell, connecting by axone *n* with muscle, *M*. (From Huber.)

Reflexes in the Cord. — To understand these reflexes as well as most of the activities of the lower part of the body it is necessary to sketch the structure of the spinal cord. The cord contains an inner mass of gray matter, somewhat like an H in shape, surrounded by columns of white matter. We may distinguish dorsal and ventral horns of the gray matter. The dorsal horns extend

back to receive axones from the spinal ganglia. The anterior horns contain large motor cells whose axones send impulses to all of the muscles. All acts, voluntary as well as reflex, are directly caused by the excitation of these cells. The columns of white matter are divided into three by these horns, the dorsal, the lateral, and the anterior. In the simple reflex the sensory impulse is received by the neurones in the dorsal root ganglion, thence is transmitted by their axones across the gray to excite the anterior horn cells, as may be seen in Figure 18. The sensory neurones also send collaterals to the anterior horn of the opposite side. These collaterals may connect directly with motor cells or they may come into contact with the dendrites of intermediate or commissural neurones, whose axones make the connections with the anterior horn cells. The points of contact of axones and dendrites are known as the synapses. These offer resistance to the passage of the impulse, and synapses differ in the amount of resistance they offer. This difference in resistance determines the course of the reflex. Thus the synapses to the motor neurones which excite the muscles of the side of the body stimulated are most permeable, and in consequence the first and usual movement is made by the member on the same side. It is only when the stimulus becomes very strong that the other member moves. The neurones in the spinal ganglia also send collaterals up and down in the cord, which connect directly or through commissural neurones with the motor neurones at various levels (Fig. 19). These make possible reflex excitation of groups of muscles above and

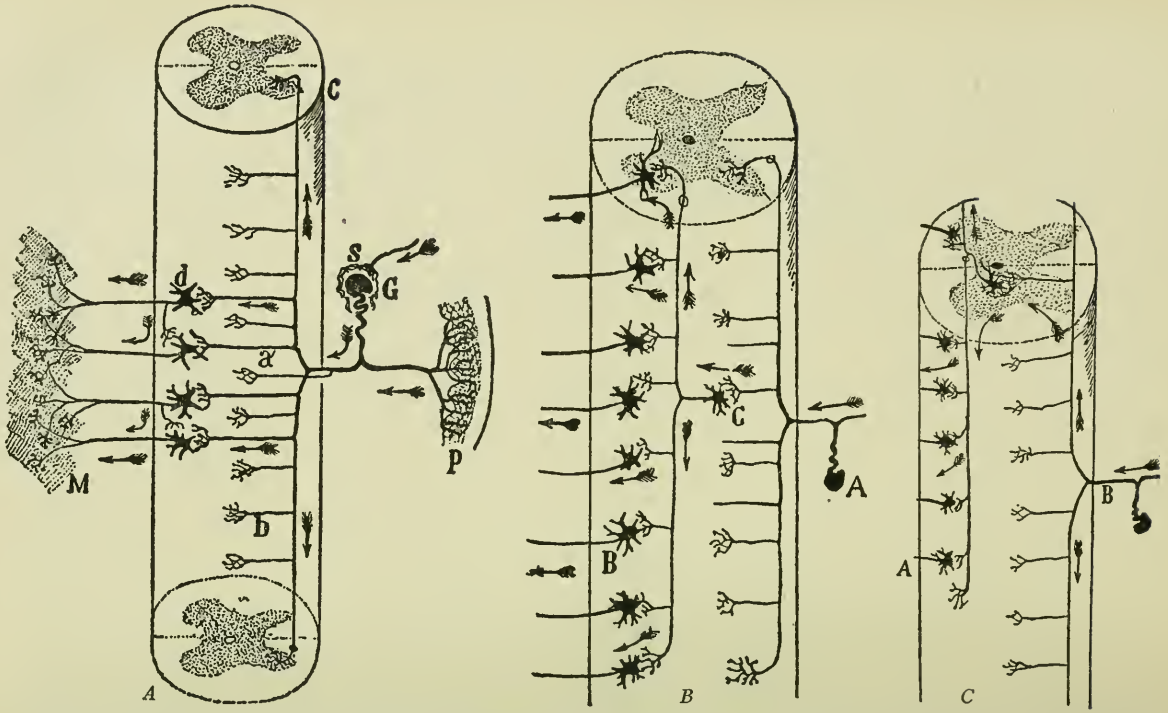

FIG. 19. — The connections in the cord by which impulses spread to different levels. *A* shows the connections by which impulses spread immediately from the sensory to motor neurones on the same side; *B* shows the connections made through an intermediate or commissural cell (*C*) to motor neurones of the same side. *C* shows paths by intermediate cell to opposite side. (From Cajal.)

below the primary reflex. These cord reflexes are all to be explained in terms of the connections between sensory and motor neurones. Selection of responses is determined by the degree of openness of the synapses between different neurones.

Tracts in the Cord. — In addition to the reflex functions of the cord, it is also an important path of communication between the periphery and the higher structures of the central nervous system, and between its own structures at different levels. The conduction paths may be divided into sensory or afferent, and motor or efferent. The sensory fibres all come, directly or indirectly, from the dorsal roots, the spinal ganglia; the motor tracts all end in the cells of the ventral horn. The different tracts are to be distinguished in terms of the higher centres to which they lead or from which they descend. The most important of the higher centres with which the cord connects are the cerebellum, which receives ascending or sensory tracts and sends down motor paths by way of the red nucleus; the corpora quadrigemina, from which small tracts descend and to which they ascend; the thalamus, to which sensory fibres go on the way to the cerebral cortex; and the cortex itself, the outer layers of the cerebrum, the structure most closely connected with consciousness. From this descend two tracts, whose fibres carry voluntary impulses to the muscles of the body. These different origins or goals give different functions. Of the afferent tracts, the most easily made out are the columns of Goll and Burdach on the dorsal side. These occupy most of the region between the dorsal horns.

The column of Goll is nearer the centre, the column of Burdach more lateral. Each is composed of fibres from the spinal ganglia, axones of neurones in the ganglia. The only difference is that the more lateral fibres come from parts of the body on approximately the same

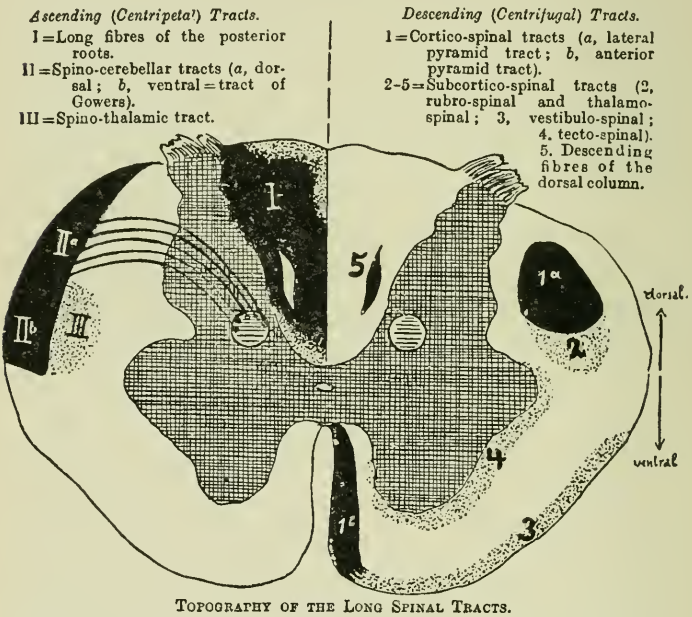

Fig. 20. — Paths of Conduction in cord. (From Bing's "Compendium of Regional Diagnosis." Published by Rebman Bros., New York.)

level, that have just entered the cord; the more central have entered lower down and been crowded toward the centre by those that come in later. The column of Goll does not exist in the lower levels of the cord. Both groups of fibres end in the medulla and there make

connections with neurones that send impulses to the thalamus and thence to the cortex. They are believed to carry sensations from the muscles. In the same area is the so-called 'comma' tract, named from its shape, which consists of collaterals from entering neurones that turn downward to connect with motor cells lower in the cord.

Other well-marked afferent tracts are found on the lateral border of the cord, the cerebellar tracts. They are divided into two, the more dorsal tract of Flechsig and the more ventral of Gowers. Both are derived from cells in the dorsal gray of the cord and carry impulses to the cerebellum. Still another sensory tract of importance lies within Gowers' tract. It is marked spino-thalamic in Figure 20 and constitutes part of the pathway from the skin to the cortex. It is believed that sensations from the skin are carried by axones from the 'T-'shaped cells in the spinal root ganglia into the gray of the cord. There they connect with a second set of neurones whose cell-bodies lie near the spinal canal. The axones from these cells cross and in part go up this spino-thalamic tract to the thalamus and thence to the cortex. The tract may also contain some fibres leading to the corpora quadrigemina.

Motor Tracts. — Of the descending or motor fibres the most important are found in the pyramidal tracts. There are two pyramidal tracts, the crossed and the uncrossed. The former, always the larger, lies just inside the Flechsig tract and is very close to the dorsal horn of gray matter. The uncrossed pyramidal tract lines the ventral fissure of the cord. Both tracts

are composed of axones of cells in the cerebrum that descend to make connection with the anterior horn cells. They carry the voluntary impulses. The first mentioned is composed of fibres that cross in the medulla, the second or anterior of fibres that have continued down on the same side but cross in the cord near the level of the cells with which they connect. Other bundles descend from the cerebellum. One coming by way of the red nucleus, the rubro-spinal (Fig. 20), lies ventral to the lateral pyramids; the other is on the ventral border. One may also mention a bundle from the corpora quadrigemina, the tecto-spinal, on the ventral border of the anterior horn. It should be noted that the names applied indicate the structures connected: the cortico-spinal tract connects cortex with cord, spino-thalamic, cord with thalamus, etc.

In addition to these long bundles running from cells at one level to others above and below, there are numerous fibres which make possible the transfer of impulses within the cord. These are numerous at the borders of the gray matter, but also occupy parts of the white area that has been assigned no other function in the above discussion. Probably some of the sensory impressions pass along these fibres on their way to the brain. They go from neurone to neurone, into the central gray and out again, instead of taking the more direct course provided by the long fibres. It should be added that the arrangement of fibres is different at different levels. The pyramidal tracts, *e.g.*, are much larger in the upper portions of the cord, as some of the fibres that appear at the upper level leave it to make connections

with the ventral cells. In fact, the ventral tract cannot be made out at all in the lower regions. The relative amount of white and gray matter also varies at different levels. The gray matter has the greatest extent in the lower lumbar region and in the cervical,

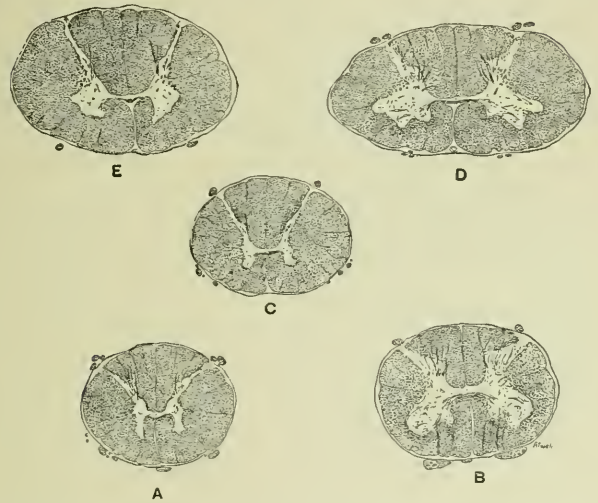

FIG. 21. — Series of sections of the cord to indicate difference in the amount of white and gray and the relative size of the cord at the different levels. *B* is a section through the lumbar enlargement, where the nerves of the legs enter and leave; *D*, a section through the cervical enlargement which supplies the arms. This figure, together with figures 23, 24, 25, and 31, was drawn by Mr. Atwell of the Anatomical Laboratory of the University of Michigan.

where the large nerves for the legs and arms enter and emerge. The cord as a whole also increases in cross section from below upward with marked swellings where the large nerves enter. See Figure 21.

Functions of the Brain Stem. — In the brain stem, from the medulla upward, the structure of the nervous

system becomes much more complicated, but the functions and general arrangements are much the same. We may distinguish three functions of the structures in the brain stem. 1. Fibres massed in well-defined tracts carry the sensory impressions upward and motor impulses downward between cord and cerebrum. 2. Masses of neurones care for the reflexes of the head in very much the same way as the cord for those of the body. Nerves lead into them from the special sense organs and from the skin of the head, and motor nerves lead out from them to the muscles of the head just as sensory nerves lead into, and motor nerves go out from, the cord. 3. The brain stem also makes wider interconnections, — serves to combine large numbers of sensory stimuli from different sense organs and to coordinate them in exciting muscles in widely distributed parts of the body to make harmonious movements. Making the different parts of the body work together is the peculiar function of the nervous system. The coördinations in the brain stem may be wider than those in the cord and those of the cerebrum are widest of all.

Important Structures in the Brain Stem. — To trace the ascending and descending paths of impressions, we need to distinguish several structures in the brain stem that serve as way stations, points where impulses are transferred from the axone of a lower neurone to the dendrites of a neurone that carries them upward, or where descending impulses are interrupted and transferred to new neurones. The first are in the medulla, the so-called nuclei of Goll and Burdach. These with the thalamus are parts of the pathway of sensory im-

pressions from the trunk and limbs. The thalamus is a structure at the base of the cerebrum which can be seen in a median section of the nervous system on the walls of the third ventricle, or from above in Figure 22. Below it to one side may be seen the internal and external geniculate bodies, and below lie the corpora quadrigemina. These are both receiving organs for certain of the fibres from eye and ear, and will be mentioned in that connection. The red nucleus lies below the back portion of the thalamus and the corpora quadrigemina within the body of the brain stem. This is part of the cerebellar system, a way station from the cerebellum to the cord. A part of the cerebellum can be seen drawn to one side in Figure 22 and the pons is directly in front of it. For our purposes these are most important structures in the brain stem.

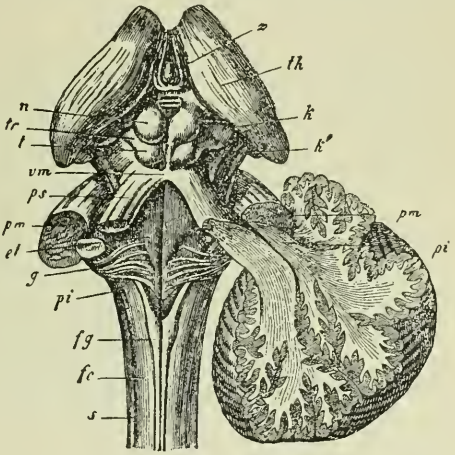

FIG. 22. — Dorsal view of brain stem. *fg*, column of Goll; *fc*, column of Burdach; *n*, anterior, *t*, posterior pair of corpora quadrigemina; *th*, thalamus; *k*, external and *k'* internal geniculate bodies; *x*, epiphysis (pineal gland); *ps*, *pm*, *pi*, are superior, middle, and inferior peduncles of the cerebellum, which may itself be seen, in part cut away and drawn to one side. (From Wundt.)

The Paths between Cord and Cortex. — Nerve currents from the sense organs of the lower body may reach the cortex by two distinct paths. The first, which probably carries only the impulses from the muscles and other deeper lying tissues, is provided by the columns of Goll and Burdach. Axones of cell bodies in the spinal gan-

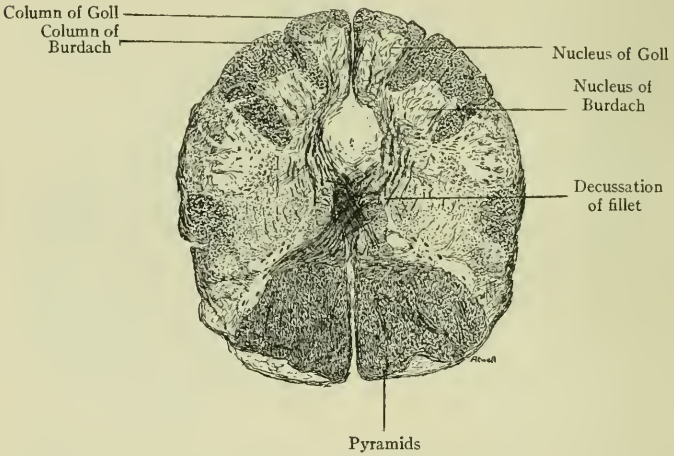

FIG. 23. — Section through the medulla to show the crossing of the sensory fibres, the axones of cells in the nuclei of Goll and Burdach. × 4.

glia ascend by these tracts to the nuclei of Goll and Burdach. Here they come into contact with dendrites of other neurones whose axones cross and then proceed up the central portion of the brain stem to the thalamus. Thence a third set of neurones carries the impulse to the cortex. Sensations from the external skin apparently travel by other spinal neurones whose axones enter the central gray of the cord and make connections with

dendrites of a second neurone whose cell body lies near the central canal. These neurones send their axones up the lateral column of the opposite side to the thalamus. The exact path that is followed in the lateral column is not definitely agreed upon. Some authors believe that there is a long tract in the anterior portion

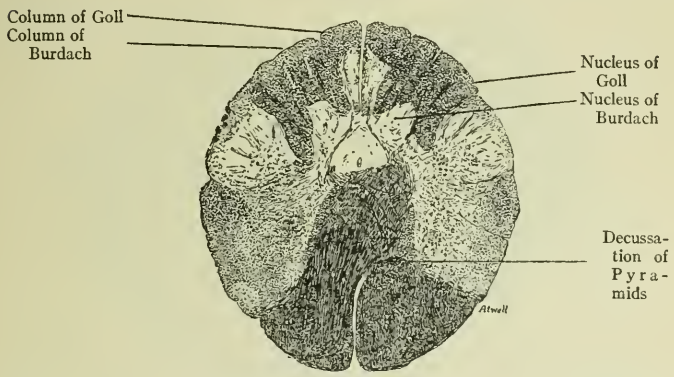

FIG. 24. — Section of the medulla to show the crossing of the pyramidal tracts, a section a little below that shown in Figure 25. × 4.

of the lateral column, the spino-thalamic tract in Figure 20; others that the path goes by way of the lateral ground bundle and perhaps may be interrupted at different levels. The axone may reënter the central gray several times, connect with a new neurone, and have that neurone continue the impulse upward. That there is a pathway upward on the side of the cord opposite to that of the sensory nerve stimulated, and that this carries the cutaneous sensations, is made very probable by observation of pathological cases. Figure 26

shows the posterior paths. The descending tracts from the cerebrum are the pyramidal tracts. The fibres that compose them are axones of cells in the motor cortex. They can be traced on the anterior portion of the brain stem through their whole course except where they intermingle with the fibres of the pons, as can be seen in Fig-

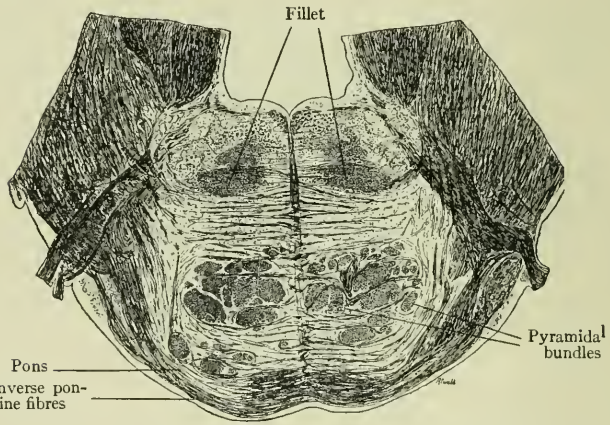

FIG. 25. — Section through pons. The interlacing of the descending pyramidal tracts, with the cross fibres of the pons, mainly connecting the lobes of the cerebellum, is clearly shown. Above, dorsal to the pons, may be seen the section of the fillet, the sensory fibres ascending from the nuclei in the medulla to the thalamus. A section of part of the fifth nerve may also be seen.

ure 25 (a section through the pons). In the medulla part of the fibres cross, as can be shown in the cross section, Figure 24. These constitute the crossed pyramidal tracts already noticed in the cord. The remaining portion, which is usually smaller and may not be present at all, continues down the anterior column and crosses in the cord at the level of the anterior

horn cells with which it is to make connection. The right hemisphere of the cortex therefore always arouses movements in the left half of the body, and *vice versa*. The course of these descending fibres also can be seen in Figure 26. It may be emphasized that two neurones alone carry the motor impulse from the cortex to the muscle, while three at least are concerned in carrying the sensory impulse upward.

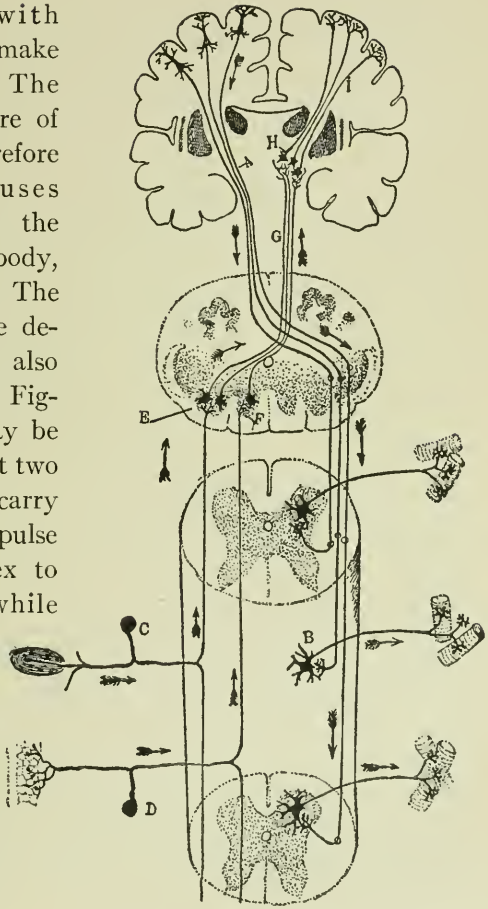

FIG. 26. — Showing schematically the ascending and descending tracts between cord and cortex. *A*, pyramidal tracts; *B*, motor cell; *C*, *D*, sensory cells; *E*, *F*, nuclei of Burdach and of Goll; *G*, central sensory path; *H*, thalamus. Only the sensory path by the posterior columns is indicated. The arrows indicate the direction of the impulse. (From Cajal.)

Roots of Cranial Nerves and their Central Connections. — The mid-brain is like the cord, also, in its

second set of functions, receiving sensory fibres and impressions, and sending out motor nerves and impulses. Unlike the continuous series of cells in the cord,

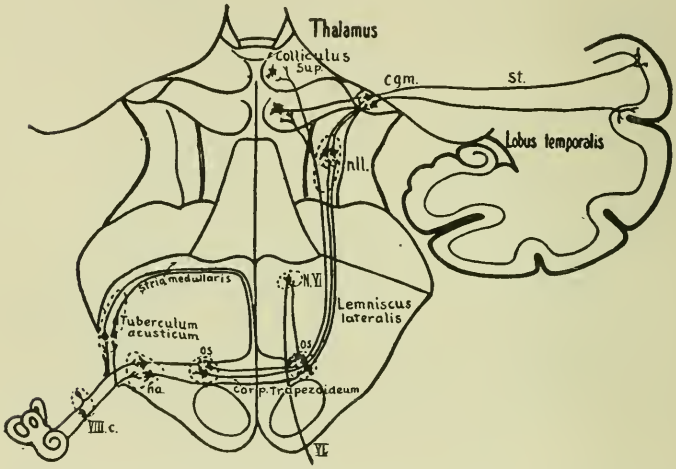

FIG. 27. — The central connections of the cochlear branch of the eighth nerve, the nerve of hearing. The first layer of neurones have their cell bodies in the spiral ganglia (VIII c) which correspond to the spinal root ganglia of the cord. Their axones connect with a second layer of neurones either in the ventral root of the eighth nerve (*na*) or in the tuberculum acusticum. The axones from this second layer of cells in both nuclei go to the superior olives (*os*), some to the one on the same side and some to the one on the opposite side. From the olives third neurones connect with a fourth layer of neurones with cells in the nucleus lemniscus lateralis (*nll*) which carry the impulses to the internal geniculate bodies (*cqm*) and thence by a fifth layer to the temporal lobe of the cerebrum. Certain of the neurones in the olives send axones to the inferior corpora quadrigemina (*colliculus inf.*) where reflex connections are made with motor roots of the brain stem. (From Rauber-Kopsch.)

the cell bodies whose dendrites and axones constitute the so-called cranial nerves are grouped in isolated masses of cells along the brain stem, the roots of the several nerves. From these roots, connections are made with

each other, with coördinating nuclei, and with cortical centres. The location and connection of the roots would require more space and the knowledge of more details of anatomy than can be given in so brief a treatment. It may be said in general that there is some approximation to the arrangement of the spinal cord in that the motor nerves frequently are anterior to the ventricles, while the sensory roots are more lateral or posterior. These sensory and motor roots also have connections with the cortex similar to those of the cord. We may trace the course to the cortex of some of the more important sensory nerves of the head. The eighth nerve, or nerve of hearing, consists of the axones from the cells in the spiral ganglia in the ear. These connect with the dendrites of cells in the root of the eighth nerve at the level of the pons; from these, new neurones carry the impulse to the superior olives on both sides, and thence by two other neurones it goes forward to the internal or median geniculate body, a body near the thalamus, and to the posterior corpora quadrigemina. From the geniculate body, one set of neurones carries the impression forward to the cortex where hearing takes place. In the posterior corpora quadrigemina reflex connections are made and cared for.

The Optic and Cutaneous Tracts. — The optic tract is very similar. The axones from the eye enter the external geniculate body and possibly the pulvinar portion of the thalamus, thence go to the cortex. The fibres that control the eye reflexes and the higher coordinations run directly to the anterior corpora quadrigemina. The fifth nerve, in part a sensory nerve for

impressions from the skin and other tissues of the head, has its cells in the Gasserian ganglion, which has much the same relation to the brain stem that the dorsal root ganglia have to the cord. Thence fibres enter the root of the nerve and a second neurone sends its axone to the thalamus, whence the third neurone makes connection with the cortex. In general the fibres of all these nerves cross either in the brain stem or, in the case of the eye whose fibres cross in part only, in the optic nerve itself. The fibres from the inner halves of the retinas cross, and finally reach the cortex on the opposite side; those from the outer halves go to the cortex on the same side. Corresponding to the pyramidal fibres that descend to the cord, motor fibres also descend from the cortex to the roots of the motor nerves of the head and make possible the voluntary control of the eyes, tongue, facial muscles, etc.

The reflex function may be illustrated by the contraction of the pupil in a bright light. As was said above, the optic nerve sends one branch to the anterior corpora quadrigemina. Thence axones proceed to the roots of the third nerve. Neurones there in turn connect with the ciliary ganglion back of the eye, which sends the impulse to the muscle in the iris. The stimulus of strong light causes the sensory impression to ascend to the corpora quadrigemina, whence it is transmitted by a new neurone to the motor root, thence, through at least two more neurones, to the muscle of the iris, whose contraction diminishes the diameter of the pupil (Fig. 30). Similar reflexes are seen in sneezing, which involves the spinal cord as well as the brain stem; in making a wry face at

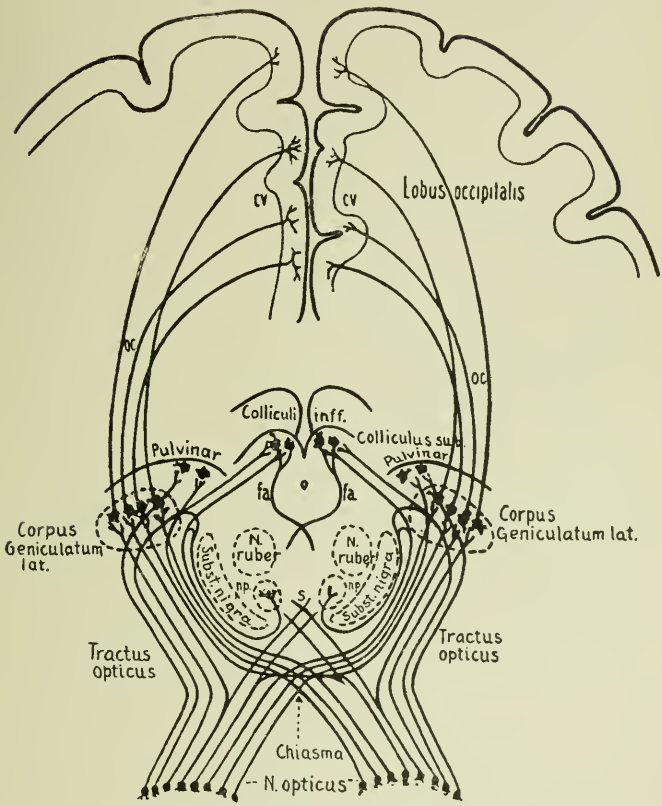

FIG. 28. — The central connections of the optic nerve. From the neurones in the eye the axones that form the optic nerve extend, after partial crossing in the chiasma, to the external geniculate body where connection is made with a second series of neurones which carry the impulse to the median surface of the occipital lobe. Other axones connect with the pulvinar of the thalamus and with anterior corpora quadrigemina (*Colliculus Sup.*) From the latter impulses are carried to the roots of the oculo-motor nerves by the path *fa*, through which reflexes are aroused. (After Bechterew.)

a bad taste, etc. In the medulla are the reflex centres that control respiration, circulation, and other vital functions. The details of the paths, so far as known, may be obtained from any good physiology.

Connections of the Cerebellum. — The third or coördinating function is most highly developed in the cerebellum and corpora quadrigemina. If we consider the connections of the cerebellum, it becomes evident that it is closely connected with the adjustment of movements. To it, as we have seen, go two sensory tracts from the cord. To it also go fibres from the vestibule of the ear, the organ for appreciating the position of the body as a whole. It receives fibres from the cortex and fibres from the ocular tracts. From it go fibres to the spinal cord by way of the red nucleus in the midbrain just below the colliculus or corpora quadrigemina. It also sends fibres to the motor nuclei of the eye muscles. These make possible the movements of the muscles of the trunk and head.

The Function of the Cerebellum. — The general function of the cerebellum is to coördinate muscular movements, particularly those involved in keeping the balance. The influence is best evidenced by the defects that appear when the cerebellum is injured. Then the body is held erect only with difficulty, if at all, the movements are jerky, the patient staggers when walking, the gait is like that of the drunken man. The balance of the body is not adjusted to the movements of the legs, the patient may lean too far forward or too far back for the immediate position of the body. Recent work makes it probable that certain parts of the cortex

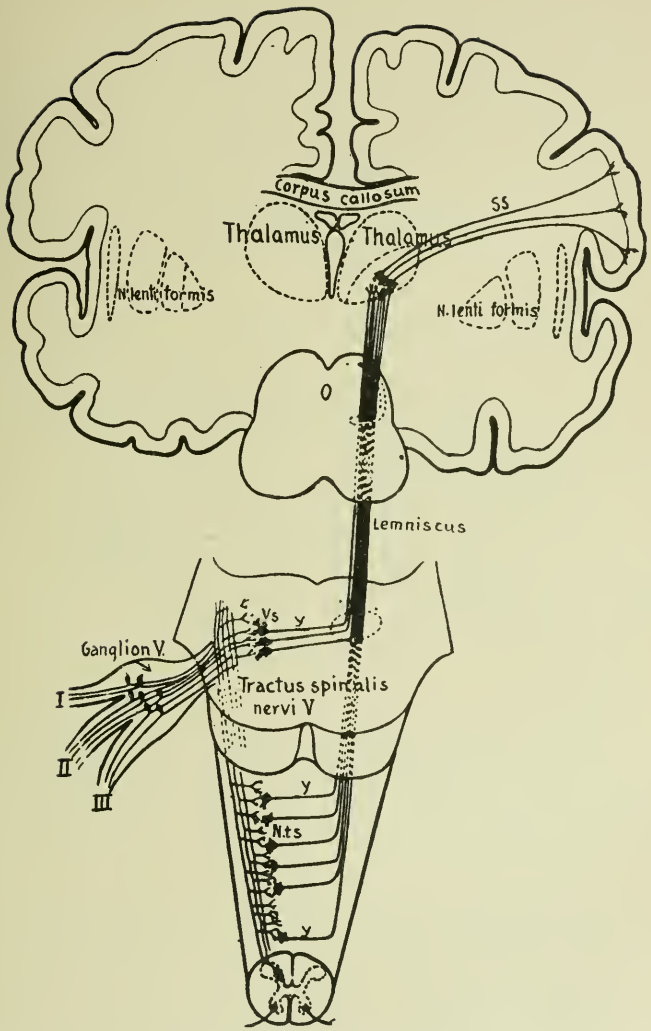

FIG. 29. — The ascending or sensory connections of the fifth nerve The relations are very similar to those of the dorsal roots of the cord. The receiving neurones have cells in the ganglion (*Ganglion V*), send axones to the sensory roots, *Vs*, which correspond to the nuclei of Goll and Burdach for the spinal nerves, whence the new neurones connect with a third layer of neurones whose cell bodies are in the thalamus and which carry the impulse to the cortex. (From Rauber-Kopsch.)

of the cerebellum take care of definite parts of the body. Streeter has established the localization by tracing the fibres, Bárány by a study of the effects of injuries of the cerebellar cortex and by direct stimulation of its surface. It is probable that the nerve currents from the various organs, skin, muscle, the vestibules of the

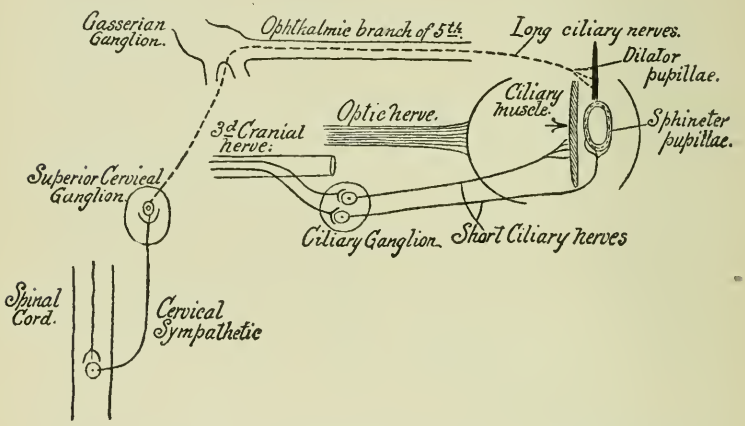

FIG. 30. — The reflex control of the size of the pupil. The impulse of dilatation takes the long path from the corpora quadrigemina down to the cord and back through the cervical sympathetic, the superior cervical ganglion, and out through a branch of the fifth nerve to the iris. The impulse to contraction makes connection through the third nerve with the ciliary ganglion, thence to the iris. (From Howell's "Physiology," after Schultz.)

ears and the eyes, which give a knowledge of position, are here united and coördinated and then sent out to the muscles, where they produce the muscular contractions that keep the balance. The cerebellum thus serves to bring together the sensory impressions concerned in movement, properly to graduate them, and to send out impulses which shall control the lower

reflexes, check some, increase others, and make all work together in proper balance.

Functions of Corpora Quadrigemina. — From the fact that the corpora quadrigemina receive fibres from skin, ear, and eye and have connections with the motor cells in the cord, as well as with the eye muscles and

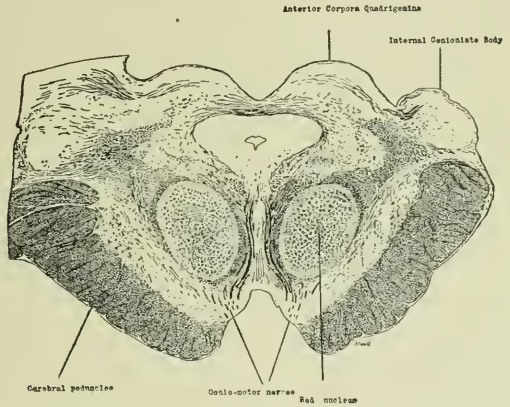

FIG. 31. — Section of mid-brain to show position of red nucleus. The anterior corpora quadrigemina and the external geniculate bodies can also be seen, as can the fibres of the third nerve, whose roots receive fibres from the corpora quadrigemina. In the lower anterior portion the descending fibres that constitute the cerebral peduncles may be seen. The pyramidal tracts are in the median portion of this structure. × 2.

other muscles of the head, it seems probable that this may be a similar coördinating center. In the lower animals the large development of these organs, as compared with the other regions of the brain, together with direct experiment, make it probable that many of the automatic movements are coördinated here. In man, however, this lower centre of coördination has been

largely overshadowed in its functions by the cerebral hemispheres, so that it plays a subordinate part. It is the intermediary for reflexes of the eyes, probably for movements of the head, but neither experiment nor pathology gives much evidence of any peculiar higher function.

CHAPTER III

THE FUNCTIONS OF THE CEREBRUM

In the cerebral hemispheres we come much closer to the problems that primarily concern psychology. Here we believe the processes which accompany consciousness in all its forms have their place, and run their course. But for an understanding of the nervous operations themselves this makes no difference. The structures and their functions can be best understood on the analogy of the lower parts of the nervous system. It is in its turn just a mass of neurones with their processes, and its functions can be represented as due to the spreading of impulses along paths within it. The problems that meet us here are those that have met us all the way up to this point. It constitutes part of the highest and most complicated path by which sensory impressions may pass over to the muscles and excite muscular contraction.

The Parts of the Cerebrum. — In the cerebrum may be distinguished three sets of structures. On the surface there is a relatively thin layer of gray matter, a series of layers of neurones with connecting processes, — the cortex. This outer coat has a much larger surface than it otherwise would because of the great number of fissures and folds that are found on its surface. These are much more developed in man than in the animals. Below the

cortical gray the interior is largely filled with white matter, — masses of fibres that run from the cortex downward to the brain stem, from one part of the hemisphere to another, or from one cortex to the other through the corpus callosum and the commissures. At the base of the cerebrum are found other masses of gray matter, the corpora striata. These are divided into a number of masses by the fibres that descend from the cortex to the lower brain, the corona radiata. The function of the ganglia at the base of the cerebrum has not been definitely determined. They have connections with the centres in the brain stem, but relatively few with the cortex. It has been supposed that they had something to do with the regulation of the temperature of the body, but no definite proof for the statement has been given.

Lobes of the Cerebrum. — The cerebrum is divided by the median fissure into two hemispheres. Each hemisphere for convenience of reference has been divided into five lobes. Three fissures in the cortex have been selected as boundaries. The most prominent is the fissure of Sylvius. It is on the side of the cerebrum and runs backward and upward from a point under the skull on a level with the eyebrows. Although the edges of this fissure are in contact, there is usually a considerable hollow below the surface, and its sides and bottom have a considerable area. This area is called the island of Reil and is usually spoken of as one of the five lobes. From a point near the middle of the Sylvian fissure, a second prominent fissure extends upward and a little backward to the median fissure and often shows on the median surface of the hemispheres. It never extends quite to

the fissure of Sylvius, but is separated from it by a fold or gyre. The fissure itself is the central fissure, or fissure of Rolando. The central fissure marks off the frontal lobe from the parietal behind it, and the Sylvian fissure separates the frontal from the temporal lobes. The parietal lobe is bounded at the back by the occipital lobe. The line of division is distinct on the median surface of the cerebrum, the so-called parieto-occipital fissure, but no boundary is to be noted on the lateral surface. The line of demarcation between the parietal and temporal lobes is even more difficult to describe. It should be said that the fissures and gyres are not the same on different brains. The Sylvian fissure can be recognized in every case, the central in practically every case, but the others are subject to considerable deviation. These five lobes, the frontal, temporal, parietal, and occipital, together with the island of Reil, are the parts into which we may think of the brain as divided, and the two important reference lines are the fissures of Sylvius and Rolando. They can all be made out in the diagram (Fig. 32).

While the functions of the cerebrum stand in closest connection with thought and with mental operations in general, the development of a knowledge of the exact connection between the parts of the cerebrum and mental action has been a matter of very slow growth. The phrenologists, Gall and Spurzheim, began it, but their methods were very loose and their conclusions so much mixed with speculation that hardly any progress was made. After their time, in the third decade of the last century, through the work of Flourens, the opinion be-

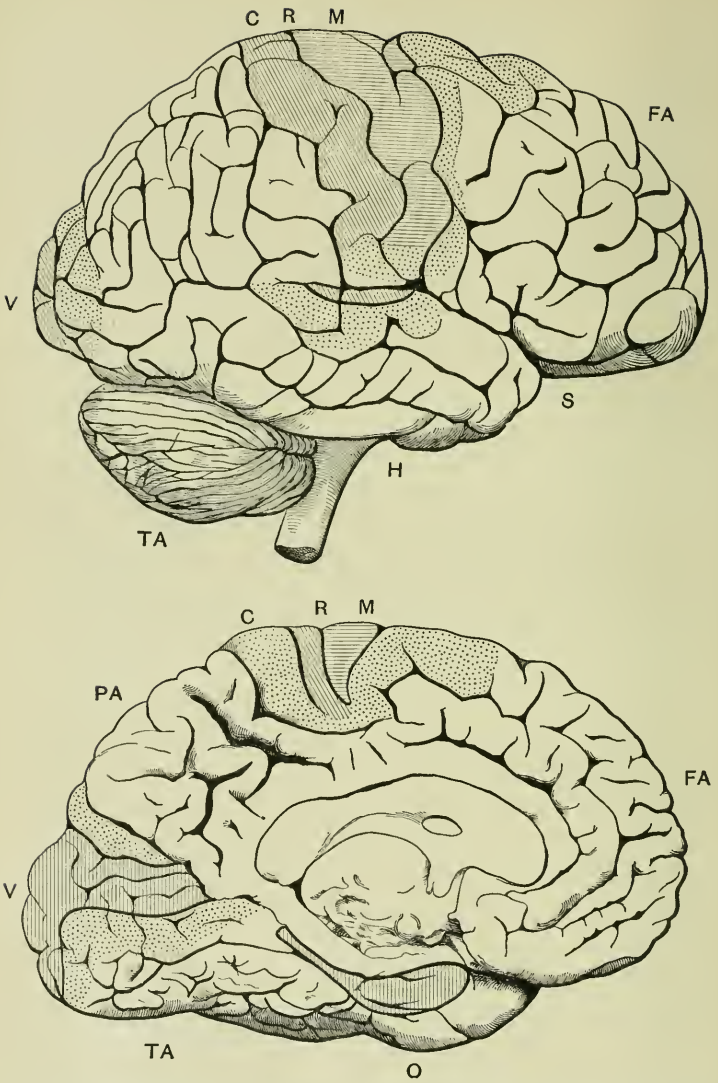

FIG. 32. — Localization of cerebral functions. The upper figure shows the outer surface of the right hemisphere; the lower, the mesial surface of the left

came fully established that the cerebrum acted as a unit, and no function could be assigned to one part rather than another. It was not until 1867 that Broca's studies of aphasia gave a suggestion that each part of the cortex has a special function, and led to studies of localization. But even in 1890 the dispute still persisted whether the brain acted as a whole, or whether different parts had different functions.

Methods of Studying Localization of Function. — The methods that have thrown light upon the subject fall in general under three heads, — experiment, observation of the effects of disease, and study of the paths and anatomical structure of the different regions. Experiments were early performed on the lower animals, in particular upon monkeys and apes, whose brains most nearly approach those of man in structure. Parts of the brain were extirpated, and when the animal had recovered from the shock of the operation, its movements were studied to see what change the operation had made. Again the brains of animals were exposed and the cortex stimulated by electric currents and the resulting

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hemisphere. In both figures the motor areas are marked by horizontal shading, the sensory by vertical shading, while the associatory areas are unshaded. The doubtful or partially sensory and motor areas are dotted. *S* is opposite the fissure of Sylvius; *R*, above the fissure of Rolando. On the mesial surface the parieto-occipital fissure is just above the shaded portion marked *V*; *M* is above the motor area; *C*, above the cutaneous and kinæsthetic area; *V* indicates the visual area; *O* is below the olfactory area. The auditory area is just below the fissure of Sylvius, above *H*. *FA* designates the frontal, *PA*, the parietal, and *TA*, the temporal association areas. There is some evidence that the dotted areas about the sensory and motor areas are areas in which particular associations are formed for the corresponding sense or movements. (The diagram embodies the results of A. W. Campbell, but has been modified in one or two respects to agree with the results of Flechsig and Cushing.)

movements were noted. In man, cases of mental defects, whether sensory or motor in character, were studied carefully and then the brain of the patient examined after death and the two series of results brought into connection with each other. It was found, *e.g.*, that a man who showed one sort of difficulty in speech would have lesions in one part of the brain, a man with another sort of defect would have another area diseased. Careful study of many cases has shown that there is a close relation between the two. The anatomical methods have resulted in tracing paths of connection between many areas, and have shown some relations that could not be demonstrated by either of the others. One method of this character that has given noteworthy results was introduced by Flechsig. He found that the different connecting paths in the brain became medullated successively as the nervous system developed, and by a method of staining brains at different ages, he was able to make one path stand out clearly among all of the others and to follow its connections with ease and certainty. Even more recently study of the cells, and of the arrangement of cells and fibres that make up different areas, has shown that areas which differ in function differ also in their finer structure.

As a result of these methods, we feel assured that the cortex is the part in which the final coördinations take place and which is most closely related to consciousness. We may also assert that the cortex constitutes part of one of the paths, by which sensations may be brought into connections with movements. If the brain is to mediate sensation and movement, one might expect

that certain parts of the cortex would stand in closer relation with the sensory, others with the motor organs. This harmonizes, too, with the fact that fibres have been traced to the cerebrum from sense organs, and from the cerebrum to the motor cells, and so to the muscles. The conjecture is confirmed by the results of brain localization. One may picture the sense organs and muscles as projected upon the cortex. The areas that receive sensory excitations and send out motor impulses are known as the projection areas. Other areas have been shown to be connected with these, to have fibres leading to and from projection areas. These are known as association areas.

The Motor Areas. — The motor areas are most definitely determined. They are in the frontal lobe just in front of the central fissure, extending from near the fissure of Sylvius upward to the median fissure and over on to the median surface. The muscles of the head and face are represented upon the lower portion, the areas for the arms, the legs, and the trunk are found in order as one proceeds upward. The details can be made out with greater accuracy from the diagram than from any description. Some of the movements can be localized with great definiteness. The thumb has a separate area for the control of its movement, and the same may be said of other important organs and muscles. These areas have been determined, in part by a study of the paralysis that comes with disease and in part by noting the movements that result from stimulating different portions of the motor cortex in animals. Then, too, in the motor areas are certain peculiar cells, the giant

pyramidal cells, and these are found to be lacking in the regions adjoining in front and behind. Most important of all is the fact that it is possible to stimulate the motor cortex of a man whose skull has been opened for examination. In a very striking operation by Dr. Cushing, the skull was opened over a large area during primary anæsthesia, then the patient was permitted to return to consciousness and the cortex stimulated while he was in a condition to report on what happened. The results obtained in this way were sufficient to convince the world of science that the motor part of the cortex is restricted to the frontal lobe rather than extending backward across the central fissure, as was thought a few years before.

The Sensory Areas. — The sensory areas are widely distributed. The area for touch is found in the parietal lobe just behind the central fissure. The definite localization of parts of the body has not been determined as it has for movement. In fact, the opinion is still held in certain quarters that movement sensations alone, *i.e.* impressions received from sense organs in muscle and tendon, have their seat in this region, while the skin senses proper are found elsewhere, but the upholders of this theory assign them to no definite place. Tracing paths and observation of injuries both coincide in giving this area to touch, whatever the final definition of that term may be. The auditory area has been located in the posterior portion of the temporal lobe, in the convolution adjoining the fissure of Sylvius, and probably extending over upon the wall of that fissure, the Island. Even more accurately determined is the region for vision. This is

found primarily in the calcarine fissure on the occipital portion of the median surface of the hemispheres. It has been located, on the basis of examination of the brains of cases of cerebral blindness, by tracing fibres from the optic tracts to it, and by examination of the brains of individuals blind from birth or early childhood. Donaldson found, *e.g.*, that the brain of Laura Bridgman was quite undeveloped in this region. In sight, the partial crossing of the fibres between the eye and the brain has been very definitely made out. If the right occipital lobe has been injured, the patient is found to be blind in the right half of both retinas, while the left halves retain their vision. Each fovea, or central point of clearest vision, seems to be represented on both hemispheres. Apparently, too, the posterior part of this area for vision receives impressions from the lower parts of the retinas, while the anterior portion receives its fibres from the upper portions. Smell, and particularly taste, are least well localized. This is primarily due to the fact that a patient may suffer from considerable defects in either sense without great inconvenience, and in consequence is less likely to complain and be carefully studied. Paths have been traced, however, from the olfactory nerve to the extreme tip of the temporal lobe, the hippocamp. This region, too, is the analogue of the portion of the cerebrum that is well developed in the lower forms that show greater capacity for smell, so that all that we know points to it as the cortical seat of the olfactory sense. Taste is supposed to be somewhere in the same region, but the evidence is even less certain than for smell. Each of these areas can be better made

out from the diagram (Fig. 32) than from verbal statement.

While the restricted areas described above are probably the more immediate sensory receiving stations in the cortex, it is not to be assumed that they are the only areas concerned. Both in sight and in hearing there is evidence that the areas about these immediate or primary stations have something to do with the sense impressions. Injuries in the temporal lobe near the primary auditory centre tend to decrease the efficiency of hearing. Also stimulation of these regions in animals calls out movements of the ears. In the occipital region, either in the cuneus or on the lateral surface, stimulation produces eye movements, and lesions are connected with partial blindness or with inability to interpret or perceive objects. The partial blindness may affect certain qualities only, or may produce inability to read. These regions may be assumed to be active in connecting and elaborating the impressions received from the sense in question, rather than as serving as the primary receiving centers.

Association Areas. — As will be seen from the diagrams, these projection areas, taken even in the wider sense of the last paragraph, include relatively small portions of the total area of the hemispheres. It was long a question what the functions of the other regions might be. Flechsig may be said to have found the answer. By his method of tracing the course of developing nerve tracts, he showed that masses of fibres led from the projection areas to the other regions of the brain, — that some were connected with few, some with

many of these regions. He inferred from this that all of the cortex not included in the projection areas serves in association. He even attempted to assign specific associatory functions to different areas. The posterior portions of the parietal and temporal lobes and parts of the occipital lobe, or the parieto-occipital association areas, he assumed to have the function of forming connections between the neighboring sense areas, and to be the seat of such associatory functions as those involved in the perception of space. The frontal lobe, so far as it is not included in the motor area, he makes the seat of the more complicated associations involved in reason and judgment. While the specific functions of different regions cannot be said to be matters of agreement, it is safe to assume that the general function of the silent areas is to make possible wide and much varied associations between the projection areas. There are formed the innumerable connections between different sensory processes and between sensory processes and movements so important for our daily life.

Functions of the Frontal Lobes. — Specific evidence of the dependence of associations upon the frontal lobes was obtained by Franz in experiments on cats and apes. When he taught his animals to make various groups of movements in combination, and then removed part of the frontal lobes, the recently formed associations were destroyed, but an act that had been well learned was not disturbed by the operation. Animals that had been operated upon and had recovered, could learn new movements, and these were again destroyed by a second operation. It might be argued that the results noted

were due, not to removal of a particular area of the brain, but to the shock or other general effects of the operation. To obviate this objection Franz removed other parts of the brain in control animals and found that the operation was without effect upon retention. He believes that his results have established the close connection of the frontal lobes with associations. Clinical observation in general supports the view that the frontal lobes are important association regions and the seat of complicated intellectual operations. When these are injured, the patient is usually incapable of the higher mental acts, is said to lose his character, to be reduced to idiocy or to a low mental state. On the other hand, considerable portions of the frontal lobe may be lost without any apparent effect upon the individual, so that the evidence is conflicting. Probably the two sets of facts are to be brought into harmony on the assumption that any part of the area may be used for associations; after associations have been formed in some one part and that part is removed, the knowledge is lost. When a portion is removed in which no connections have been made, no change in the animal can be noted.

Aphasia. — The coöperation of the various areas of the cerebrum in mental operations can be well illustrated by a study of the facts of aphasia, which we may undertake as a final review. This is one of the most familiar defects, and is also illuminating because speech stands in such close connection with all of the other mental operations. By aphasia is meant the loss of speech due to any lesion of the brain. Closely connected with it are agraphia or loss of ability to write, and alexia or in-

ability to read. They may be treated together, as they are closely connected in use and in the areas of the brain affected, as well as in the principles of explanation. Two forms of aphasia are ordinarily distinguished. One is characterized by inability to produce the vocal movements in a coördinated fashion, and has been connected since Broca's time with a lesion in the third frontal convolution, an area in front of the immediate motor centres for the muscles of the head and throat. The other is sensory aphasia, first reported by Wernicke in 1874. It is more closely connected with inability to hear, or to think of the word, a word deafness, and has been connected with injury to the auditory centre and of the immediately contiguous areas of the temporal lobes.

Partial Aphasias. — In addition to the cases which show complete loss of function together with loss of capacity to hear or to anticipate the pronunciation of words, one must distinguish instances in which the patient can hear mentally, can reproduce words to himself, but cannot hear when words are spoken. On the other hand, there are patients who can recall the 'feeling' of words as they are spoken, can have all the antecedents of speech, but cannot speak. In these cases lesions have been found in the subcortical regions which affect the projection fibres on the path to the muscles. All the cortical processes go on as usual but the connections with sense organ and with muscles are broken. Other distinctions can be made in sensory aphasia, in particular between injury of the primary receiving centre and the adjoining elaborating or memory areas. Thus, according

to Adolph Meyer, when the first temporal gyre on the side next the island is injured, ' word-deafness ' results. In case the lower portion of the gyre is injured, on the other hand, words are spoken hit or miss, what is called a ' word-salad ' is frequent, memory for words seems disturbed but not destroyed. Still another element must be added to give a complete picture. Other than

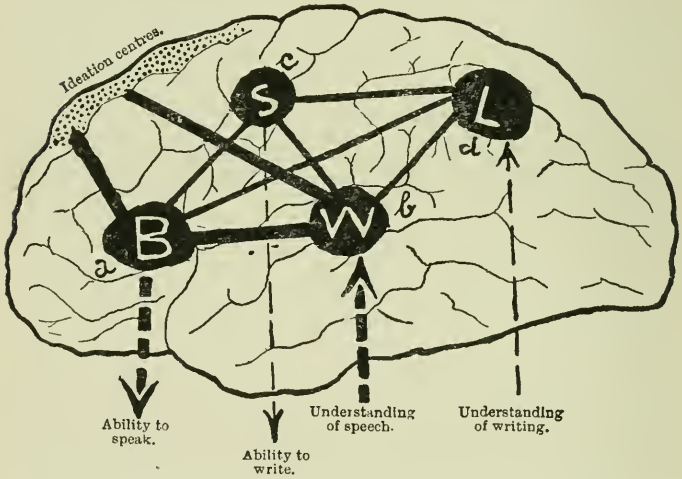

FIG. 33. — Diagram of speech areas. (From Bing, *op. cit.*)

the auditory memories are necessary before the words can be understood in their completeness. This has been pictured by Wernicke and others as a process of connecting the word with a concept in a concept centre. The concept centre is probably too simple a way of disposing of the process, but it is necessary to connect the word or sound with a large number of other experiences before

it is understood. With suitable reservations this may be interpreted to mean that the auditory impression makes many associations before it is transferred to the motor centre. If these connections be injured, repetition of sounds heard is possible, but there is no under-

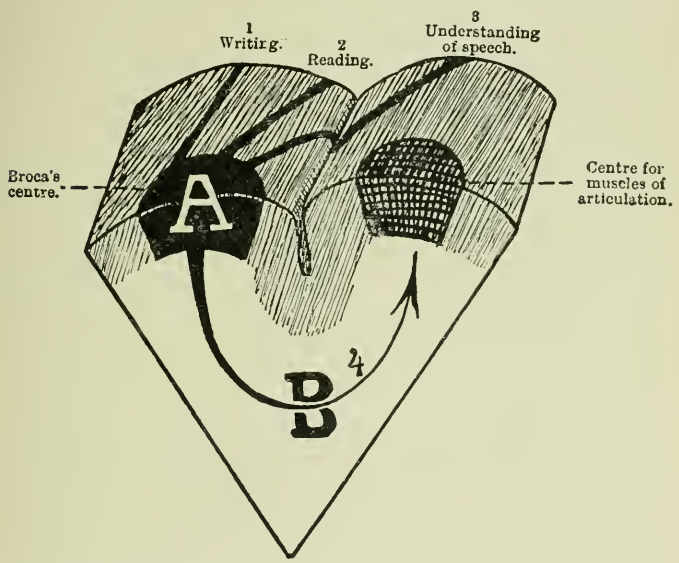

FIG. 34. — Showing connections broken in cortical and subcortical motor aphasia. In the former, 1, 2, and 3 are interrupted; in the latter only 4. (From Bing, "Regional Diagnosis." Rebmann Bros., New York.)

standing of what is heard, and no proper control of what is said.

Five operations may be thought of as necessary for speech: 1. the reception of the sound in the primary centre for hearing; 2. its elaboration in the association region about the primary centre; 3. more complete elaboration by reference to other than auditory experi-

ences (transfer to the hypothetical concept centre); 4. arousal of the coördinated motor impulses in Broca's centre; 5. conduction of these to the separate motor centres, from which the impulses are sent down to the muscles. The functions of areas 4 and 5 are related in very much the same way that a higher coördinating region, such as the cerebellum, is related to the activity of a mere reflex centre. In the latter, a single muscle or muscle group is made to contract by stimulation; in the former, a large number of sensory stimuli are coördinated and distributed to each of the different motor centres to cause just the right amount of contraction in each muscle at just the right time, — to marshal the different component movements to produce a satisfactory total result. The disappearance of any of these centres, or of the connections between them, produces aphasia, or in less serious cases, paraphasia.

Other centres that have been connected with the speech processes are the reading centre, which is localized on the lateral occipital lobe, and the writing centre. The reading centre has the same relation to the primary visual centre as has the auditory speech centre to the primary auditory centre. It may be imagined to be the region in which the visual pictures of words are supplemented with memories and thereby understood. When the centre is injured, reading becomes impossible or inaccurate. The writing centre is not so generally accepted now as it was a decade ago. There have been a few cases of an inability to write with retention of ability to speak, but it is assumed that these were due to injury below the cortex or to paralysis of the arms due to

lesions in the cortical area for the control of arm movements, rather than to the destruction of a single centre for the coördination of the specific movements involved in writing, similar to Broca's centre for speech. It should be said, in leaving the discussion of speech functions, that the cases are by no means so clear cut as one might wish. There is much contradiction and confusion in the observation made which is only partially harmonized in such a schematism as that given above. Still this may be regarded as a simple picture of what takes place.

The Left Cerebrum Dominant. — It should be emphasized that, in right-handed individuals at least, the speech functions have their seat in one hemisphere only, the left. In cases of injury to the right brain in what corresponds to Broca's or Wernicke's centres, speech suffers no injury. Apparently this is only one phase of the general fact that in right-handed individuals the left hemisphere cares for the more important and delicate coördinations, while, with exceptions, the right hemisphere dominates in the left-handed individuals. If an injury be done to the right hemisphere in the third frontal convolution but the primary motor centres be not injured, the speech functions are not disturbed. Similarly when the motor region in the left hemisphere is injured but the right is unaffected, it is found that the left hand is rendered incapable of delicate movements, although there is no sign of paralysis and the coarser movements are unaffected. Liepmann found one case in which both hemispheres were normal, but where there was a lesion in the corpus callosum, the mass of fibres

which connects one cortex with the other (Fig. 35). In this case, the right hand was normal, the left what is called apraxic, — that is, delicate movements could not be carried through with accuracy. These cases indicate

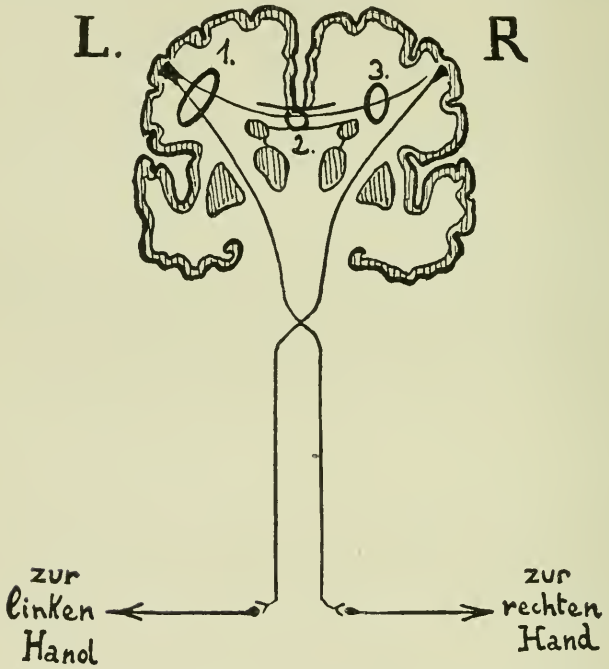

FIG. 35. — Showing the lesions that might break the connections between the left and right hemispheres and so produce apraxia of the left hand. If the lesion is at 1, the right hand will be paralyzed as well, if at 2 or 3 only apraxia of the left hand is caused. (From Bing, *op. cit.*)

that the highest coördinations, whether in speech or in manual exercises, are accomplished in the left hemisphere. It has been suggested that right-handedness is really left-brainedness, and *vice versa*.

Restitution of Function. — Interesting, too, in this connection is the fact of restitution of function in cases of cerebral lesions. Not infrequently an aphasic will show marked improvement, sometimes almost complete recovery, with no betterment of the lesion. In surgical cases the patient will frequently show considerable paralysis immediately after part of the cortex has been removed, but with the passage of time his movements will become normal again. Various speculations have been indulged in to explain this phenomenon, such as that the function is taken over by the other hemisphere, that the paralysis is due to shock, and when that passes, the old structures regain their activities, or in general that some other part of the nervous system can take over the work. No one of these theories has received general acceptance, nor can any be said to be altogether satisfactory, but it is important in several connections to note that there is a considerable degree of flexibility in function exhibited by many of the nervous structures. Surgeons have joined part of the central end of a flexor nerve to the peripheral end of an injured extensor nerve and, when regeneration has taken place, the nerve and its central connections perform the new function without a hitch. In cases of destruction of one path through the cord, as in infantile paralysis, it is found that new paths will develop and the paralysis disappear in time, provided only that the muscle be kept from degenerating while new paths are being developed. Vicarious functioning, replacing of one structure by others, seems to be a fairly general law of nervous action, although much remains to be learned of the limits and details of the process.

Résumé of Nervous Functions. — In brief, then, we see that in the nervous system, the action of all parts depends upon a transfer of sensory impulse to motor neurones, and the consequent excitation of muscular movements. There are three levels in the nervous system at which the transfer from sensory to motor organs may take place: 1. at the level of the simple reflex in the cord or brain stem; 2. in the higher coördination centres in the brain stem, the cerebellum, and the corpora quadrigemina; and 3. in the cortex. As one passes to the higher levels, the number of sensory impulses concerned in guiding movements becomes greater, and in consequence the movements become more accurately adjusted to the environment, to the circumstances of the moment. In the cortex, the association centres provide regions where all sense impressions may be brought into connection with each other and with retained impressions, and where all combine to control movements. Action is in the light of past as well as of present experience. In consequence, the highest forms of adaptation are possible. Aside, however, from the increasing complexity of interaction, the highest and the lowest forms of nervous action follow the same laws. The control of the path taken by the impulses through its structures may also be explained on the same general principles.

Perhaps the best notion of these principles is given by a theory elaborated by Professor Sherrington. This regards the course of an impression through the nervous system as determined by the ease or difficulty with which nerve processes may pass from one neurone or nerve element to another, the amount of resistance at the

synapses. This has already been briefly mentioned in the preceding chapter. The great number of synapses that may be crossed can be seen in Figure 36, which shows the large number of collaterals and end brushes of a single neurone from the cerebellum of a rat.

The final explanation of why one synapse should be more permeable than another, and why the same synapse

FIG. 36. — The numerous points of connection of a neurone from the cerebellum of a rat. (Cajal.)

should be more easily crossed at one time than at another, has been the subject of much discussion and is not completely agreed upon as yet. The earliest and simplest explanation grew out of the picture of the nervous system as a colony of individual cells each like an amœba, which could control in some degree the extension and withdrawing of processes. Just as a group of amœbæ that happened to be in contact might send out pseudopods and touch each other at different times and places, so the neurones might on occasion

send out or increase the length of the dendrites until they came into contact with the end brushes of the neighboring axones. It was further assumed that when physical contact was present between the neurones, a nervous impulse might pass, while at other times the path was blocked. Some authorities asserted that the dendrites were shorter in animals killed by an anæsthetic than in others. The theory was used to explain sleep as due to a blocking of all the pathways to consciousness. Later consideration has led to the abandonment of the theory. It would make all action of the nervous system depend upon chance activities or arbitrary activities in the separate cells, rather than upon the way they were affected from without, or by other cells. Sleep might be satisfactorily explained, but on the theory it would never be possible to waken the individual until the neurones were ready to put out their dendrites again.

Sherrington is convinced from a careful study of the times required for the reflex movements under different conditions, that we must think of the synapse as constituted by continuous tissue, but also as containing a membrane of some sort which offers a resistance to the passage of the impulse, and that the degree of resistance is determined by the degree of permeability of the membrane. The neurones would always be in contact, the reflex path is always continuous, but the impulse is impeded at the point of contact between axone and dendrite.

If we may be satisfied with the theory, we still have to ask why one synapse should be more permeable than another. In the lower centres it may be assumed that

the openness of certain synapses and the closed conditions of others is inherited, that it either is present at birth or appears soon after as a result of the inherited predisposition. Few reflexes are perfect at first, — they improve for days or even weeks in the higher animals. At first the child does not accurately touch a point stimulated although there is usually some indefinite waving of the arms. Many of the more complicated reflexes and instincts make their appearance late, although probably the development comes in large part as a result of growth rather than of learning. The paths open at birth determine a relatively larger proportion of the total number of paths in the cord and midbrain than in the cortex, but probably form a large number of the total connections even in the adult cortex, and the general lines of connection are pretty well laid down there.

Habit a Change in the Synapse. — The connections that develop in the life of the individual as a result of learning are due to changes that take place in the character of the membrane. What this change is is not determined and cannot be, so long as we do not know what the nature of the opposition in the membrane may be. We do know that the more often two neurones are excited together or in immediate succession, the greater is the likelihood that the activity of one will extend to the other. All learning, whether in the formation of habits or in the connection of sensory impressions in sensory learning, is due to this reduced resistance. The laws that govern the reduction of resistance from use are known in some degree from the observations of the behavior of the

organism, but our theory takes us only to the point where we may say that learning is due to some sort of reduction in the resistance offered by the synapse to the passage of the nervous impulse.

Our picture of the action of the cortex, as of the cord, is that all is determined by the openness of paths, by the synapses. The passage of the impulse from sense organ to muscle is, as has been emphasized repeatedly, the explanation of all function, whether in cord or in cerebrum. The difference between the two is that there are more open paths in the latter over which any impulse may pass and that for the most part these paths have been opened by use, by the earlier activities of the organism. It should also be emphasized that many different stimuli coöperate in producing the activities that result from the action of the cortex, many more than act together in any of the lower centres or organs. The coöperation is made possible by the fact that many of the paths have common parts; in fact, that the motor part of the path is common to very many different acts. In the majority of cases the same muscles, and even the same groups of muscles, are used. The excitation of the motor path may be aroused by a number of sensory impressions, and the various impressions may be thought of as coöperating in the final action. What is even more important in this connection is that each sensory impression may be connected with several motor or intermediate neurones, and the action which results when the sensory impression is received must depend upon the openness of the various synapses, of paths leading to the possible motor organs that may be excited. Where

very large numbers of stimuli are presenting themselves at every moment, there must be a large amount of co-ordination, of reciprocal influence, to determine which of the possible movements is actually made. The strongest impression and the one whose neurone has the most open synapses between it and the motor neurones will determine the action.

Facilitation and Inhibition. — In addition to this mere openness of paths and the greater strength of the impressions, coördination seems to imply mutual interaction between the neurones of one path and those of another. Sherrington and others have demonstrated two forms in which one path or series of neurones may act upon others. One, the more direct, is some process of making easier the path for one response by another set of neurones active at the same time. This is very common. It may be illustrated very easily by the knee-jerk. You are familiar with the fact that if you strike sharply the tendon below the knee-cap when one leg is crossed over the other, the foot will give a kick. It has been shown that the kick will be much stronger if the hands are clenched at the time the blow is given. The clenching of itself would not produce the kick, but it prepares the way for, or facilitates, the response when the blow is given. This may be pictured as a preparatory reduction of the resistance of the synapse which makes the impulse pass more easily, and hence with greater intensity, when the suitable stimulus is applied. More striking is the second fact of inhibition. Certain paths when active prevent the action of others, or reduce their liability to response. Sherrington has demonstrated this phenomenon in the

case of many reflexes, such, for example, as the general reduction of the strength of the reflexes of the cord when it is in connection with the cerebrum. After the cerebrum has been removed and the animal has recovered from the shock of the operation, all reflexes are exaggerated, a fact explained on the assumption that in the normal animal all lower reflexes are inhibited by the higher centres. More interesting for our immediate purpose is the fact, fully established by Sherrington and Hering, that the flexor and extensor centres in the cortex mutually inhibit each other. They removed the flexor muscles of a member, placed the animal in such a position that there was a tendency for flexion, — it was supported only by the extensor muscles, *e.g.*, — and noted that the member was lowered when the flexor centre was stimulated. This they explained by an inhibition of the cortical centre of the extensor muscle from the flexor centre which reduced the tonus of the extensor, and so permitted the member to be flexed. This was also demonstrated on the antagonistic eye-muscles. If the internal muscle of the eye were severed and the cortical centre for that muscle were stimulated, the eye would turn as it does upon stimulation of that centre when the muscle is intact. This mutual checking of antagonistic movements prevents any possibility of interference between groups of muscles in voluntary action, — makes impossible any pulling against each other that might come were no such interrelation present. Inhibition is assumed by Sherrington to be due to the action of one set of neurones upon a synapse somewhere along the other path of discharge. The activity of that set of

neurones, in some way as yet unknown, makes the membrane at the synapse much less permeable, and so prevents the discharge of the impulse across it.

These processes of facilitation and inhibition are quite as essential to the interaction of various stimuli in the cortex as in the lower centres. As will be seen from time to time in considering the mental processes, the most important and striking fact is the wide interaction of mental processes. It is seldom that an act or a thought is controlled merely by a single stimulus or even by the stimuli that are being received at the moment of action. The laws of facilitation and inhibition of one set of cortical activities by others that are going on simultaneously in other paths and in other areas, are needed if we are to obtain any accurate picture of cortical action. The details of this interaction can be left to the particular fields in which they are to be applied.

The relation of consciousness to the total action of the brain may be briefly mentioned. On the physical side, the action of the nervous system may be thought of as the passage of chemical or electrical changes or processes through its various structures. These are present not at a single place but everywhere throughout the mass of neurones, — hundreds, if not thousands, of separate sensor-motor arcs are carrying impulses at the same time — for the muscles not only are moved by nerve impulses when they move, but are also kept in slight or tonic contraction by the constant action of the neurones. But of all these activities, only relatively few, perhaps not more than one group at a time, are accompanied by clear consciousness. The others do their work without

being noticed. If they contribute at all to consciousness, it is only by modifying the total mass in some slight degree. They are silent servants, or their addition is lost in the complex. The general rule is that consciousness attaches to activities which are performed for the first time, or which offer special difficulties. As movements are repeated, they gradually cease to attract attention, and usually by the time they can be carried out effectively, only the intention or the first beginnings of the act are conscious. There is no evidence, however, that the impulse follows any distinctively new path after it ceases to be conscious, that a voluntary act is first carried out by the cortex, *e.g.*, and then by the lower centres. It seems probable rather that consciousness drops away as the impulse crosses the synapses more easily. The paths followed are still the same when the action becomes easy, but we are not aware of the activity.

The Relation of Body and Mind. — Much of modern psychology since Descartes has dealt with the problem of how the mental processes are related to these nervous processes we have just been discussing. The problem originated from the fact that behavior may be studied in two ways, from without and from within. When one attempts to study man with the scalpel and the instruments of the physiologist, he deals always with the physical man, with nerve and nerve cell, with white matter and gray matter, but he never finds any trace of sensation, of the inner experience. On the other hand, when one studies the mental states and devotes oneself to what can be seen in one's own consciousness, alone, one never finds any immediate evidence of nerve cells.

For the most part investigators have preferred one or the other of these approaches to the facts of mind, — few men have given due credit to both. Even where each attracts the interest of the same man, it is seldom that both are combined in a single statement, or completely harmonized. More frequently one is entirely subordinated and to all intents and purposes we are given an explanation that is either completely materialistic or spiritualistic. Most writers compromise, and while they subordinate one of the two series they still leave it as an accompaniment but without real force, a sort of ghost of mind or of body which merely follows the activity of the other but has no influence upon it.

Very generally, at present, the two lines of approach are recognized and both of the resulting series of experiences are accepted as real. The problem that makes trouble is how to think of the relation between them. Two theories of what this relation is may be recognized. One takes the natural attitude that the two series interact as do series of physical events; that when a sense impression is received, it is transmitted to the brain by the paths we have indicated, and that in the brain it in some way gives rise to the incorporeal process we know as sensation or knowledge, in the same way that the vibration of a sounding body may give rise to vibrations in the air. Similarly, it is assumed on the other side that voluntary processes may produce changes in the nervous system and so in the physical universe, just as simply as do physical forces in other physical objects. This theory of the relation of body and mind is known as interactionism.

Another theory equally current at present is known as psycho-physical parallelism. It is an expression of the conservatism of modern thinkers in refusing to assert any particular sort of relation between body and mind. The mental series is assumed to constitute one train of events which can be explained in terms of earlier mental events; the physical series, the changes in nervous elements, is made entirely distinct, and it is assumed that they can be completely explained in terms of the antecedent physiological processes. The relation between the two series either is left unexplained or it is said positively that there is no interaction between them. When one recalls an event, *e.g.*, one would run through the series of ideas until the proper associate presented itself. On the physical side, the series in recall would depend upon the connections that had been established between neurones in different sensory areas of the cortex, and the action resulting from the recall would be due to the transfer of some nervous excitation from a sensory area to the corresponding motor area. When it is asked, however, how it comes that the nervous processes are always accompanied by the mental states, one of two answers is made. The more extreme men assert that there is no present connection between the two series of events. Each runs its own course because of some of the antecedent events within itself, but nothing that happens in the other can influence it. The two are kept together because they go at the same rate, rather than because of any cross connection between them. Members of the other school are less dogmatic in the negative. They assert merely that they do not know the nature of

the connection, not that there is no connection between the two series.

The evidence adduced by the upholders of each theory is largely negative. The negative considerations upon which parallelism is based are the fact that one never can appreciate both series at the same time, can see nothing pass, and that the two series of events are not at all comparable. One cannot think of a thought moving a stone, or, in Clifford's term, it seems absurd to assert that two cars are coupled by the bond of affection between guide and guard, and to speak of a thought making any change in nerve cells is on exactly that level. At times the argument is given a more formal turn in the assertion that to assume interaction is in violation of the doctrine of the conservation of energy. If the physical series is to be regarded as a closed system of energy, it can neither give off energy to the mental states as is required if sensations are to be caused, nor can it be changed by mental states, as would be necessary if human volitions were to exert an influence upon the nerve cells. In passing upon these objections, one must remember, however, that the doctrine of conservation is itself only a principle that has been set up for convenience, and must be given up if it should cease to harmonize with facts, and also that it may be possible in the future to include the mental world in some wider system of relations in which the mental and the physical shall be brought together. The objection is more formal than real. We come back, then, to the original assertion that we cannot make a single observation that will include a mental event and the physical event that causes

it or is caused by it, and in consequence can obtain not even an approximate picture of how one is related to the other. There is not even a good analogy for the connection, and most explanations are analogies.

On the other hand, the interactionist insists with great firmness that mere failure to see what happens when two events succeed each other uniformly, does not prove that they do not stand in some active relation, even in causal relation to each other. It is very seldom, if ever, that one can actually know that some force has passed from one object to another, or can know anything of what has taken place between them. An actual tracing of energy relations is the exception rather than the rule. In other words, the relation between the mental and the physical series of events is no more unknown than is any other active relation. There is therefore no more objection to regarding the psycho-physical relation as causal than the relation between heating and expansion or any other simple physical relation. Physical cause is itself not understood, and, if one goes deep enough, is as much a mystery as the relation of mind and body. While one may grant all this very readily, it does not necessarily follow that to change from one side to the other too often and too quickly — to introduce mental elements into the physical series and physical into the mental series — may not give rise to vagueness and uncertainty. As a matter of fact, while one may admit that there are causal interconnections between nervous system and mind, it is also true that many arguments become vague if the speaker jumps from one series to the other for an explanation. While we shall admit that mind and body un-

doubtedly interact, we shall endeavor as far as possible to keep the explanation of physical states in terms of antecedent physical states, and the explanation of mental states in terms of antecedent mental states, and assume as little interaction between the series as is possible. It is necessary to accept an effect of the sense organs and sensory neurones upon consciousness to understand the material of consciousness and an influence of voluntary processes on muscles if we are to understand action. Aside from these, however, clearness demands that all mixing of the two sets of explanations be avoided.

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CHAPTER IV

SENSATION — VISION

We have seen from our discussion of the action of the nervous system that all nervous action starts in sensation and leads to movement. The first half of this assertion is to be our guiding principle in discussing the qualities of consciousness. All the materials of our knowledge are derived from sensation. We have just as many different sorts of consciousness as we have qualities of sensation, and consciousness persists apparently only so long as impressions are playing upon our sense organs. The old sensationalists, Hobbes and Locke, *e.g.*, insisted that there could be nothing in mind that had not previously been in sense. While we do not to-day accept the principle quite so literally as they did, yet it is easy to see that the fundamental qualities of mind are derived altogether from the external senses. One can imagine no color or sound that has not at some time been seen or heard; or, to put it more conservatively, one can call to mind no quality of any kind that has not at one time come through the senses. One cannot picture the color of an ultra-violet light, or think what it would be like if one were suddenly to develop a sense organ that might be affected by it, nor can one think how the magnet might affect one if

some sense organ should be developed to respond to it. Memory, imagination, and reasoning are limited in the qualities that they make use of to the bare materials of sense. They may recombine them, they may make use of the sense materials in new ways, but they can add no new qualities.

Classification of Sensations. — The qualities of sensation might conceivably depend either upon the nature of the stimulus or upon the nature of the receiving organ. The popular mind accepts the former, but most psychologists believe that they are determined by the character of the sense organ or the connected portions of the nervous system, by the nature of the sensory ends that are turned outward to the physical world. That the nature of the sensation does not depend altogether upon the stimulus is evident from the fact that different stimuli produce the same sensation when they affect the same sort of nerves. Thus we shall see that heat waves, pressure, and heat or its lack all produce the sensation of cold when they act upon a cold spot on the skin. On the other hand, the same stimulus, an electric current, *e.g.*, produces a different sensation as it acts upon different kinds of sense organs, cold on a cold spot, light on the retina, etc. These facts and others seem to show fairly conclusively that the nature of the sensation is determined by the receiving organ, rather than by the stimulus that is applied; by the character of the receiving tissue that has been developed, rather than by the character of the outside world. If this be accepted provisionally, it furnishes a convenient means of classifying sensations.

Could one but determine the different sorts of sense ends that come to the surface of the body or are imbedded in its substance, one would also have a complete list of the possible sensations. In practice one usually discriminates the sense quality first and later discovers the sense organ, but the classification nevertheless is assumed to be in terms of the sense organ. We may accept for the moment the general principle that the number of sense qualities is determined by the number of sorts of sensory tissue that can be stimulated.

The classification of sensations still offers some difficulties, since the fundamental kinds of sense ends must be grouped in some way for convenience of treatment. In certain cases the similar nerves are combined in some one organ. Thus in the eye are thousands of nerve ends stimulated by the same physical forces, and giving rise to similar sensations. In the skin, on the other hand, sense ends of one kind are scattered indifferently over its surface, and while popularly we speak of the skin as the sense organ of touch, there are really at least four different kinds of sensation received from the skin. Taste and smell offer an inconsistency of the opposite sort. The organs are distinct, but the stimuli are closely similar and the qualities of sensation are not discriminated by the popular mind, yet science and common sense follow the organ rather than the quality in making them distinct sense departments. One may say, then, that in classifying sense qualities, the organ provides the first means of grouping, and within the organ the subdivisions may be either in terms of the classes of stimuli, or of the qualities of sensation, or of both.

When one attempts to enumerate all possible sorts of mental qualities or sensations, one sees very quickly that there are various kinds of differences that are not on exactly the same level. It is not possible to arrange all the different kinds of sensation from any organ in a single series, members of which shall differ from each other in one respect only. Thus in sound, we may distinguish differences of pitch and also differences of loudness. These vary independently. A high tone may be either loud or faint. These different ways in which sensations may vary are called the attributes of sensation. How many attributes there are is by no means a matter of agreement. All agree that one must distinguish differences in quality from differences in intensity. The quality may be said roughly to depend upon the specific character of the sense organ stimulated, while the intensity depends upon the degree to which the organ is stimulated. There are probably exceptions to both of these statements. In light, for example, the strength of stimulus probably in part determines the organ stimulated. Faint lights are probably seen by one set of organs, bright lights by another. In the eye, too, even with bright lights, variation in physical intensity is not distinguished from change in quality of excitation. The grays correspond to changes in strength of light but the untrained observer puts them on the same level with change in color. Black, white, and gray are popularly regarded as colors. But in all other senses, the distinction in quality and intensity offers little difficulty, and these two attributes are recognized by practically all psychologists.

Attributes of Sensation. — More difficult it is, however, to dispose of some of the other attributes sometimes ascribed to sensations. Thus every sensation, or more truly every object, possesses extent, and every event occupies time, has duration. Many authorities speak of extent and duration as attributes of sensation, as fundamental ways in which sensations may vary. In the simplest cases, these ways of varying seem immediate and unanalyzable, but in many more instances it is possible to show that the appreciation both of extent and of duration depends upon more complicated mental operations. They belong rather to the object than to the sensation as such. In consequence it is more convenient to treat them both under the head of perception, as a process of mental elaboration of sensations, rather than as an immediate characteristic of the elementary sensation. Very much the same statement may be made of clearness and feeling tone, regarded by some authorities as attributes. It is at least a question whether feeling is not independent of sensation and equally primary as a mental state. Clearness is a change induced in sensations as a result of their connections in consciousness, not an attribute of sensations themselves. Whether we are to regard them as irreducible parts of sensations, or as independent elements, or as accidents of the ways of receiving the sensation, can be best discussed in a later chapter. For the present we may content ourselves with the statement that sensations vary in specific quality which depends primarily upon the nature of the receiving end organ, secondarily upon the character of the stimu-

lus; and in intensity, which, in its turn, is dependent upon the amount of stimulation that affects the sense organ. Considering qualities alone, the sensations fall into certain series, marked by continuous change in some one respect. It is impossible, however, to find similar continuous changes from series to series. Thus colors show a continuous series of tone; sounds show a continuous series of pitches; but there is no gradation from sound to sight. Through each quality runs a series of intensities which is regularly graduated from zero to a maximum. We shall discuss first the qualities in their dependence upon the organ and the stimulus, then the intensities.

The Stimuli for Vision. — We may begin with the most important, if one of the most complicated senses, vision. The physical stimuli for sight are vibrations in the ether ranging from 400 to 800 $\mu\mu$ [1] in length. Helmholtz under favorable circumstances saw rays as long as 835 λ and as short as 318 λ. There was probably some error from fluorescence at the short wave end, since the retina has a certain amount of fluorescence of its own. Between these limits lies the visible spectrum from red to violet. We give names to different qualities, but it is somewhat difficult to say just where one color changes into another, since the names given are not matters of agreement. The physical relations have little significance for the sensation quality. They afford little suggestion of the nature or condition of color qualities and very few of the laws of color can be stated

[1] $\mu\mu$ means thousandths of a thousandth of a millimetre. This is usually expressed as λ.

in terms of the wave lengths of light. We must turn from the physical to the physiological for an explanation of the phenomena that interest us. For this we must consider the essential features of the structure of the eye.

The Eye and its Appendages. — The eye is a part of the brain that has come to the surface of the body in the course of its development, has increased the primary sensitiveness of nerve tissue to light by the development of new photochemical substances, and has gained a system of lenses and grown protective coats, and acquired a mounting that permits of ready turning in all directions. The eyes are mounted in deep conical sockets in the skull, where they are well protected. The eyeball is kept in its place in the socket by loose fibres of connective tissue, by a padding of fat, and by the muscles that turn it. To prevent foreign particles from entering the socket, the front is closed by the conjunctiva, a membrane continuous with the inner lining of the eyelids and the outer surface of the eyeball. Three pairs of muscles turn it. The discussion of their action may well be left over to the chapter on space perception, for it is in that connection that their action is important. The padding of fat, the conjunctiva, and the loose connective tissue at once hold the centre of the eye fairly well fixed, and at the same time permit it to turn easily about its centre.

The Structure of the Eye. — The eyeball is approximately a sphere a little less than an inch in diameter (23–24 mm.). The spherical shape is given it by the outer or sclerotic coat, which is kept distended by the

fluids within, submitted to constant pressure by the general circulation. This pressure amounts to about 25 mm. of mercury in the normal individual. The eyeball has three principal coats. The sclerotic is a tough protective coat of connective tissue. Inside the sclerotic is the choroid coat, made up mostly of blood vessels with some muscles and nerve fibres. Still farther within is the retina, the nervous structure and true sense organ. Between the choroid and the retina is a layer of large pigment cells regarded by some authorities as belonging to the choroid, by others as an independent intermediate coat, and by still others as a part of the retina. The difference of opinion is probably due to the fact that the cells are in a different position in the light-adapted and the dark-adapted eye. When the eye has been for a long time in the light, the cells are well down in the outer coat of the retina, and adhere to it. In the dark-adapted eye, on the other hand, they are well outside and come away from it freely when the choroid is stripped off. They are relatively large hexagonal cells, and like the black paint on the inside of a camera insure the absorption of errant light rays.

Each of these coats shows modifications in some part. The sclerotic coat in the front of the eye has a shorter radius of curvature, is transparent, and bulges forward as a part of the lens system. Here it is called the cornea. It can be seen to protrude from the sclerotic if one will look across the eye of another. Back of the cornea is a chamber filled with a watery fluid. This is the anterior chamber, and the fluid, the aqueous humor. In this chamber is an extension of the choroid coat, the

iris, which is not attached to the sclerotic or cornea, but extends across the anterior chamber in the aqueous

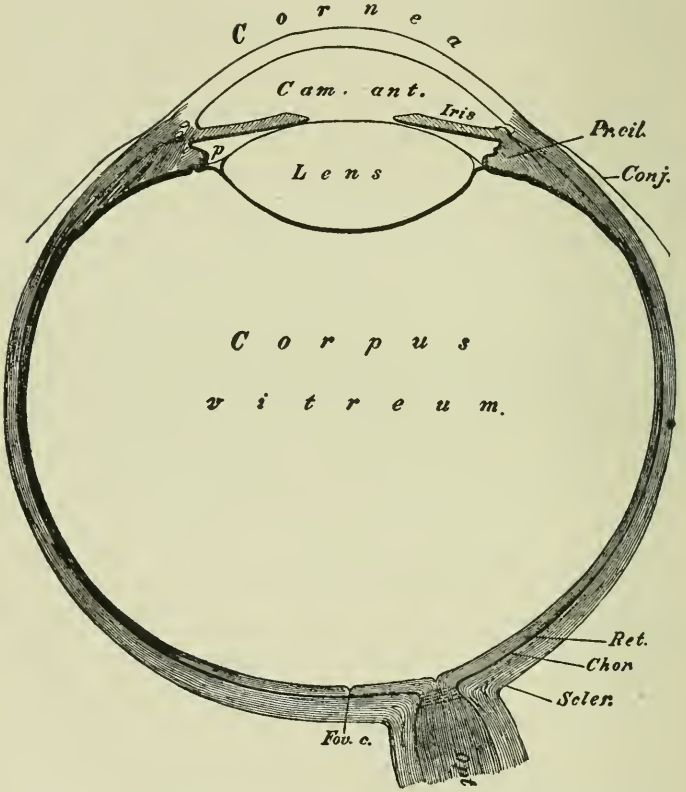

FIG. 37.—Section of the eye; *Scler.*, sclerotic coat; *Chor.*, choroid; *Ret.*, retina; *Opt.*, optic nerve; *Fov. c.*, foves; *Pr. cil.*, the ciliary muscle or ciliary process; *conj.*, conjunctiva; *Cam. ant.*, the anterior chamber; *corpus vitreum*, the vitreous humor that fills the main body of the eye. (From Angell's "Psychology.")

humor. In its centre is a hole, the pupil. The iris gives the color that is regarded popularly as characteristic

of the eye. In the dark types, it is much pigmented and passes for black or brown; blue and gray eyes are less pigmented. The size of the pupil is determined by the relative degree of contraction of two muscles or sets of muscles: (1) a muscle with radial fibres, the dilator of the pupil, and (2) the sphincter, a muscle with circular fibres. These are controlled reflexly by the degree of stimulation of the optic nerve. The course of the reflex in constriction was traced on page 58. Dilation involves a reflex through a long path down to the cord and back through the cervical sympathetic nerve and superior sympathetic ganglion to the eye. The widespread course of the pupillary reflex makes it very important in the diagnosis of nervous diseases in general. It is affected by lesions in many different structures. In the normal individual, the constriction takes place promptly on increase of illumination, while dilation is relatively slow because of the long course through the sympathetic nerves. The function is in part protective by reducing strong lights, but also has somewhat the effect of the diaphragm of a camera. It gives better definition because it stops down the pupil when the light is strong enough to permit and when the light is faint it admits more. Constriction of the pupil also accompanies accommodation to near objects.

The Mechanism of Accommodation. — Back of the iris and directly against it is the lens, the most important of the optical mechanisms. It consists of a large number of layers. The front surface of the lens has in youth a natural radius of curvature of 4.8 mm., the posterior of 4.6 mm. Ordinarily, however, it is held flattened

by the strain of the suspensory ligament. This extends from the ciliary processes on the ciliary muscle to the edge and the front and back surfaces of the lens. The lens with its attachments constitutes the mechanism of accommodation — makes possible focussing upon objects at different distances. The active agent is the ciliary muscle. It is attached to the sclerotic coat near the angle formed by the increasing curvature of

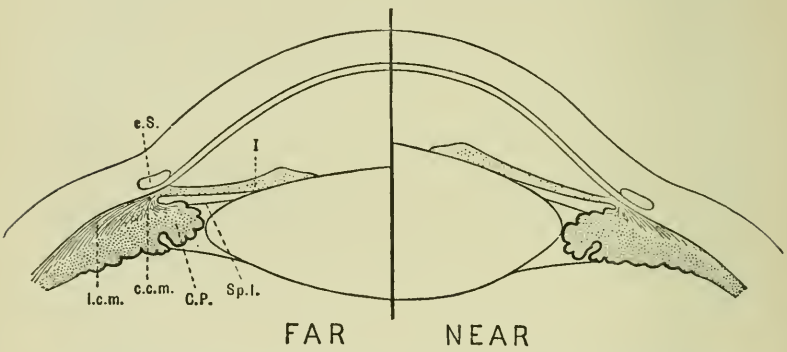

FIG. 38. — Change in lens and ciliary muscle in accommodation. Left shows accommodation for distant, right for near objects. (From Foster's Physiology.)

the cornea, and the fibres run back to lose themselves in the structure of the choroid coat. The suspensory ligament is attached to the side of the muscle instead of the end as are the tendons of other muscles, so that the contraction of the muscle means relaxation of tension on the suspensory ligament rather than increase of tension. When the tension of the suspensory ligament is released, the lens resumes its normal shape owing to its elasticity. As one grows older, the lens becomes less and less elastic, and accommodation practically dis-

appears between 45 and 55 years. Back of the lens is the large posterior chamber of the eye, filled with the vitreous humor, so called because it has the consistency of molten glass. This fills the cavity between the retina and the lens.

Dioptrics of the Eye. — Regarded as an optical system, the function of the eye is to project an image of an object upon the retina. The important refracting surfaces are three, the front surface of the cornea and the front and back surfaces of the lens. The indices of refraction of the cornea, and of the aqueous and vitreous humors, are approximately identical, and each is approximately the same as that of water, — 1.337. The refractive index of the lens in practical effect is 1.437. Calculation of the optical efficiency of the system of lenses in the eye from these figures, assuming an average radius of curvature of the cornea of 8 mm., of the front surface of the lens of 10 mm., and of the back surface of 6 mm., gives it a value of from 60 to 66 diopters.[1] An eye with a length of axis of 22 mm. must have a strength of 66 diopters if the rays are to be focussed upon the retina. It is assumed that the normal eye has a strength of 64.50 D and that the nodal point, the point through which all light rays may be assumed to pass, is 15.5 mm. from the retina and about 7.3 back of the cornea. For most calculations one may use the reduced eye of Listing, a simpler structure with a re-

[1] A diopter is defined as the strength of a lens that will bring parallel rays to a focus at a distance of one metre. The number of diopters of a lens is determined by dividing one metre by the length of its principal focus. A lens that brings parallel rays to a focus at 20 mm. has a strength of 50 diopters.

fractive system that has the same optical function as the eye. This has a single surface 2.1 mm. back of the surface of the cornea, with a radius of curvature of 5.2 mm. and a refractive index of 1.33. The size of the retinal image cast by objects in the outside world and other relations of light rays are sufficiently accurately determined for most purposes if one assumes that the nodal point is 15.5 mm. in front of the retina, and that principal rays pass through it on the way to the retina.

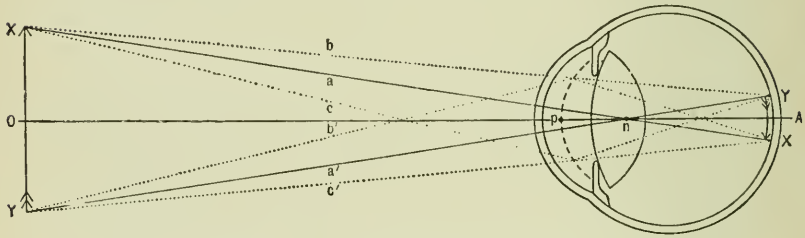

FIG. 39. — The formation of the retinal image. Shows refraction of three rays of light from *X* and *Y* that focusses them on the retina, and the inversion of the object. *P* is refracting surface of reduced eye. (From Foster's "Physiology.")

The Structure of the Retina. — The retina is practically a part of the central nervous system. It is a very thin coat of nerve tissue from .3 to .35 mm. in thickness. If we accept the neurone theory, the retina is composed of three layers of neurones, one with the modified sensory epithelium, the rods and cones, which receive the stimulation; one intermediate layer, the bipolar cells; and one whose cell bodies are the large ganglion cells nearest the vitreous humor. In the older histologies it is said that there are ten coats, but these are composed of the various masses of cell bodies,

axones, dendrites, and synapses between the neurones, and need not concern us now that we can see their relations to the neurones. The rods and cones are farthest away from the light directly in front of the layer of pigment cells and the choroid coat. The cones are relatively short and thick, from 4–6 μ (μ = .001 mm.) in diameter and 30–40 μ long. The rods are longer and more slender, 2–4 μ across, and 40–60 μ long. They are crowded about as closely together as is possible, so that the distance from centre to centre of the elements is not much greater than the diameter of the single element. In both the rods and the cones can be distinguished an outer section and an inner section. Just at the base of the cones and a little distance away from the rods is a swelling that probably constitutes the cell of the neurone. The axones of the rods and cones come into contact with the dendrites of the bipolar cells, and the axones of these in turn with the dendrites of the large ganglion cells. In the fovea it is said that a cone connects with a single bipolar cell and that in turn with only one ganglion cell. Thus the impulse from each cone in the fovea is kept separate all the way to the brain. In other portions single bipolar cells make connections with more than one rod or cone. In addition to these direct lines of connection with the central nervous system, there is a layer of cells between the rods and cones and the bipolar cells which serves to connect different rods and cones horizontally. It is possible, even probable, that some of the spreading of impulses in contrast and irradiation takes place over these horizontal cells. In addition to these nerve cells

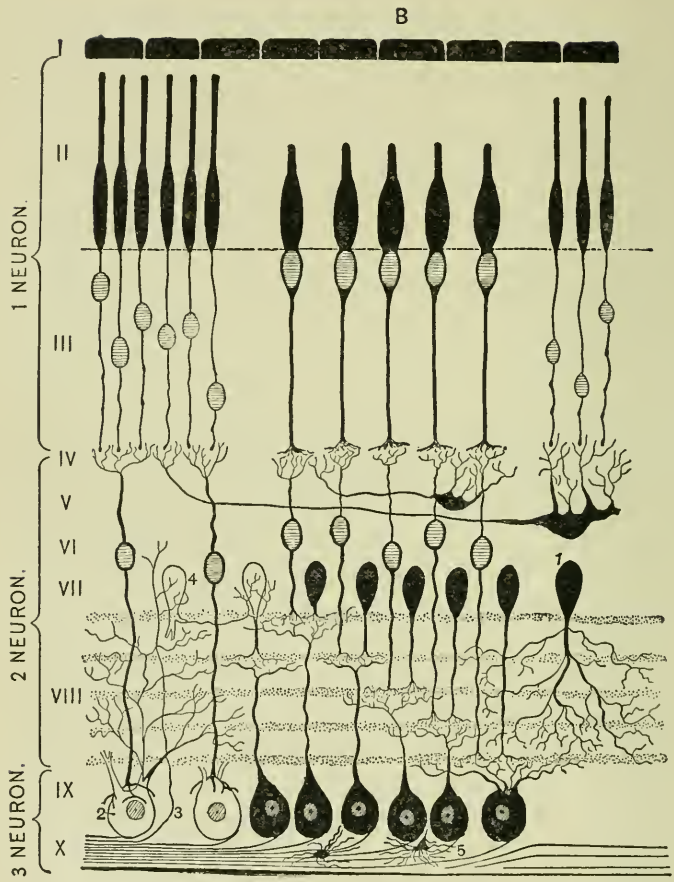

FIG. 40. — Section of the retina, showing the neurones. (After Cajal, from Howell's "Physiology.")

there are everywhere in the retina supporting cells of non-nervous tissue, the so-called Müller cells. In the innermost layer are fibres, the axones of the ganglion

cells, which unite to constitute the optic nerve and carry impulses to the cerebral nervous system.

Fovea and Blind Spot. — Certain parts of the retina show modifications from this general arrangement that make them of particular interest. One of these, the fovea, lies near the centre of the retina. It is the point of clearest vision, the point turned toward objects we desire to see distinctly. As its name implies, it is a pit or depression in the retina made by a drawing apart of

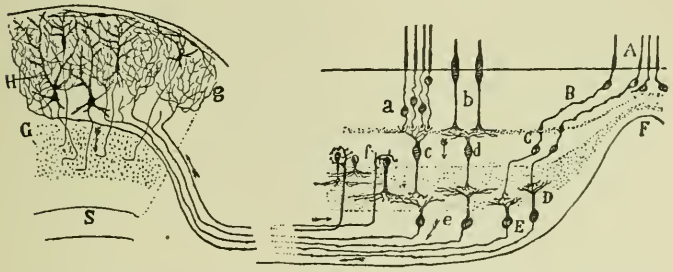

FIG. 41. — Section of the fovea. It may be seen that the axones of the cones extend toward the periphery to make connection with bipolar and ganglion cells. On the left may be seen the central cells to which the visual impulse is carried. (From Cajal.)

the front coats of the retina. This pit is due to the fact that axones which lead off from the cones go towards the periphery of the fovea, and the bipolar and ganglion cells with their axones and the blood vessels which supply the region are to one side of the cones rather than in front of them, — between them and the light as in other portions of the retina. The cones are here nearest the surface, and light need not pass through so much retinal tissue. In the fovea, too, are found only cones, and these are as long and slender as rods, so that the centres are

only about 2–4 μ apart. In the neighborhood of the fovea the retina has a yellowish tinge. The fovea is 0.3–0.4 mm. wide at the bottom and 0.5–0.75 at the top. The yellow spot is much larger, some six millimetres in diameter. In the literature the fovea, point of clearest vision, and yellow spot are used almost interchangeably. This is only approximately accurate, as the dimensions of the yellow spot and fovea show. As one proceeds from the fovea, the rods become relatively more numerous, the cones less numerous, until at the periphery the cones are almost entirely lacking. A third local difference that offers something of interest is the area at which the optic nerve leaves the eye. This contains no rods or cones, but only the fibres, axones of the large ganglion cells, which unite to form the optic nerve. It is an area about 1.5 mm. (4°–6°) in diameter, about 5 mm. (15°) to the nasal side of the fovea.

The Rods and Cones are the Organs of Vision. — There is very good evidence that the rods and cones are the organs of vision. 1. Vision is absent where the rods and cones are lacking at the entrance of the optic nerve. 2. The shadows of the blood vessels in the outer coat of the retina may be seen under suitable conditions, and H. Müller has measured the distance of these blood vessels from the perceiving organs by a method of triangulation based on the apparent displacement of their shadows with known motion of the light outside. He found that the blood vessels were from 0.17–0.33 mm. from the perceiving coat, and measurements of the actual distance in the retina

between blood vessels and the layer of rods and cones was from 0.2 and 0.3 mm.

The problem as to what changes go on in the retina when it is stimulated, what actually makes one see, has aroused much discussion. Two changes can be seen to take place. One is a change in the color of the pigment in the rods. The retina of a frog killed in the light has a very light color. If, however, it be killed after being kept a long time in the dark, the rods have a delicate purple hue. Pictures may be taken with the retina of a rabbit. If the rabbit looks for a little time at the window of a dark room in which it is placed, then is killed and the retina fixed as one would fix a photographic plate, a picture of the window can be seen on the retina. Such an optogram is shown in Figure 42. It has also been demonstrated by a similar method that the rods contract in a bright light, and that the pigment cells in the layer just outside of the retina move in between the outer joints of the rods. Of these changes only the bleaching of the visual purple has been given any meaning, and that, as we shall see, acts only as a sensitizer of the retina. The positions may be compared in Figure 43.

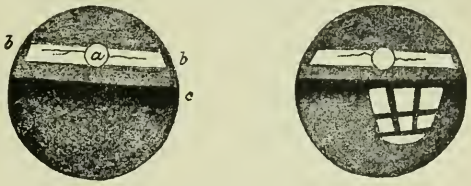

FIG. 42. — Optogram. *1* shows the normal appearance of the rabbit's retina; *2* shows the condition when the rabbit has been permitted to look at the window of the dark room and then is killed while still in the dark and the retina fixed as a photographic negative is fixed.

The Qualities of Vision. — All theories of vision have been based upon a study of visual phenomena rather than on a study of the physiological processes. Explanations of physiological processes develop from the facts of sight rather than the other way round. The sensations from the eye may be divided into four different series. The first corresponds to the pure spectral colors at maximum saturation, the series ranging from red to violet together with the purples. These vary with the wave length. The second, the brightness or achromatic series, corresponds to the different intensities of all wave lengths as in sunlight or, strictly, of suitably mixed wave lengths, and the sensation series varies from black to white through the grays. The third series is the effect of change in the intensity of a single wave length and ranges from the most saturated or complete color to black at a slight intensity of stimulus, and again from the most saturated color to a whitish hue, at the maximum intensity. The fourth series corresponds to the mixture of a single wave length with grays of the same intensity. The sensations that result range from the pure color to a gray. The amount of the admixture determines what is called the degree of saturation of the color. The pure color is saturated, and the greater the amount of gray, the less the saturation. The last two variations are frequently mixed;

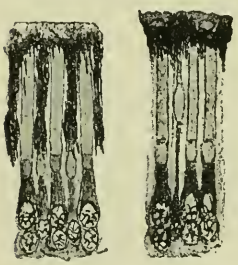

FIG. 43. — Showing position of pigment cells. In the dark adapted eye (right) they are outside of the outer layer of the rods and cones; in bright adapted eye (left) they are well down between the rods and cones. (From Siven and Wendt.)

saturation and brightness frequently change together. The entire series of color qualities may be represented on a double pyramid (Fig. 44). The color tones lie along the sides of the square. Black stands at the bottom, white at the apex, and the series of grays lies along the connecting line through the centre. On the outside of the figure the shades of the various colors corresponding to reduced intensity of the pure lights are represented from the central square downward, the tints corresponding to increased intensity, from that base upward. The various degrees of saturation are represented by distances on the base of the pyramid from the outer square, where lie the spectral colors, to the centre that represents the neutral gray. The color tones are more and more mixed with the neutral tint from the circumference inward until color altogether disappears in the centre. The fact that the color may be mixed with a gray of greater or less brightness and so reduced in saturation and changed in brightness at the same time, can be represented on the pyramid by lines from the base of our double pyramid to a point on the central line at any distance above or below the

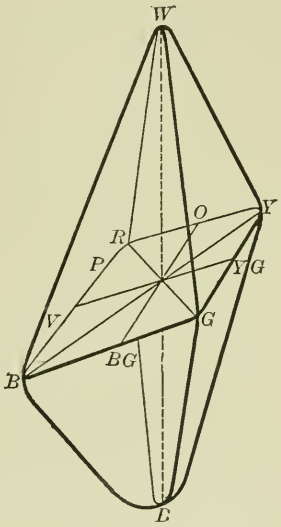

FIG. 44. — Color Pyramid. (From Titchener's "Textbook of Psychology.")

base. That the spectral colors are of *different* brightnesses has been represented by tilting the square base more or less, making the yellow corner higher than the blue. We shall treat each of these series of sensations separately as far as possible.

We may begin with the colors of the spectrum. The spectrum is a continuous series of colors which shade one into the other with no breaks readily observed at the first glance. The one fact that has been emphasized by direct observation is that there are certain turning points in the apparently continuous series, points where one quality gradually disappears and another gradually begins to show itself. Thus, at the long-wave end, red predominates. As one moves the eye toward the short-wave end, red gradually becomes less and less pronounced until it is finally lost at 588 λ in the yellow, which has also been present in some degree from the beginning. When red disappears, green begins to appear and gradually increases. In the meantime yellow gradually diminishes in amount until it disappears at 526 λ and blue takes its place. Still another of these critical points occurs farther on at 484 λ, where the green disappears and is replaced by red in the violet colors at the short-wave end.

Color Mixture. — The terms we have used imply that there are in the spectrum relatively few simple colors and that any two of these may be distinguished in the intermediate colors. All theories, ancient and modern, have been an attempt to discover just what these simple colors are and to determine how they combine to produce the other colors. Needless to say there has not

been agreement as to how many or what these elementary processes are, but these differences may best be discussed after the facts have been presented. The first experimental indication of the fact that most colors are compound is obtained from color mixing. Colors may be mixed, either by having two different wave lengths of light fall upon the same spot of the retina at the same time, or, more conveniently, by rotating disks of the colors to be mixed so rapidly that one color appears before the effect of the other has disappeared. Both methods give approximately the same results. The first law of color mixture is that two spectral colors when mixed give a color that lies between them in the spectrum. When the colors lie near together, the resulting color approaches saturation; as the two components come from points farther apart, the saturation becomes less. Not only may we obtain spectral colors from the mixture of spectral colors, but, if different proportions of the extreme ends of the spectrum be mixed, colors are produced that correspond to no single wave length but are nevertheless true color tones of a high degree of saturation. These are the purples, mauves, and other similar qualities. Since they grade from red to violet, they may be regarded as filling the gap between the two ends of the spectrum. For sensation, then, the series of colors can best be pictured as a closed figure rather than as a straight line. The direct psychological evidence for this is that the two ends of the spectrum are more alike than are points nearer together. Violet has a greater similarity to red than has any spectral color beyond pure yellow, and the two ends

of the spectrum may be joined by suitable mixtures of the extreme colors. For this reason, among others, the colors have been schematically arranged either on a circle, on a triangle, or on a square. The circle represents merely the fact that the ends of the spectrum tend to come together; the other two indicate the number of primary colors that are assumed to combine to produce the whole series. Those who assume that there are three simple colors prefer to represent the series by a triangle with red at one angle, green at one, and blue at the other. The upholders of the four-color theory, on the contrary, choose a square, with red, green, yellow, and blue at the corners.

Primary Colors. — That the spectral colors are derived from a relatively small number of simple colors seems demonstrated, first, by the fact that colors similar to those produced on the retina by single wave lengths of light can also be excited by stimulating the retina with two different wave lengths suitably chosen; and secondly by the fact that the purples, which physically are always mixed colors, seem just as true colors as those produced by a single wave length. Irrespective of the number and character of the simple colors, it is assumed by all theories that there are separate substances or sense ends in the retina for each of the primary colors, and that these simple structures or processes combine their effects in some way in the production of composite colors. It is further asserted that other than the primary colors aroused by single wave lengths are really mixed colors, physiologically. Thus blue-green in the spectrum produced by a single wave length is

physiologically compound, due to the simultaneous action of the blue and the green organ or process. Just how many primary colors there are and what they are are still matters of some dispute upon which these facts of color mixture throw no light. Helmholtz assumed that there were three primary colors, red, green, and blue or violet. Helmholtz based his selection upon the fact that all the other spectral colors may be obtained from these three in a high degree of saturation. Hering, on the contrary, asserted that there must be four primary colors, red, yellow, green, and blue. Hering's red is purplish, his green, bluish. We shall follow this usage since physiological tests show these to be the primary red and green.

The Nature of White Light. — A second law of color mixing is that certain spectral colors when mixed in the right proportions produce, not an intermediate color, but a colorless sensation, a gray, whose shade depends upon the amplitude of the light waves. Colors which cancel each other in this way are called complementary colors. For the four-color theories, this fact serves further to define the primary colors, since Hering assumes that the primary colors are also complementary. Red is the complement of green, and blue of yellow. For the three-color theory no evidence is gained in support of the primacy of the colors it assumes, but it does make it necessary to select certain colors that, taken together, shall make white or gray, shall be colorless. This brings us to a consideration of the physical nature of white light with its darker tones of gray and black. There are no single wave lengths that give rise to these

brightnesses. They are always compounded out of a number of wave lengths. In the sunlight all the colors of the spectrum are present, but the result for sensation is a somewhat yellowish white, owing to dominance of the yellow lights.

Complementary Colors. — To produce white the simple wave lengths must be present in the right number and proportion. Both theories assume that white or gray light is produced when all of their primary colors are present in the proper balance. For Helmholtz all must excite the retina at the same time, while Hering asserts that white is seen whenever both components of either of his complementary pairs of simple colors are active in the same degree, and that they are all present in the spectrum in almost the proper balance to neutralize each other. This explains the fact mentioned in connection with the first law, that spectral colors when mixed do not give a saturated color and that the farther apart they are in the spectrum the less saturated they become. Colors farther apart are more nearly complementary, and so more white is present in the compound. The list of wave lengths of colors that are complementary is given in Table I. It will be seen that no simple statement can be made of the relation of the wave lengths of complementary colors. Each must be determined for itself. As a result of the facts stated in this law it may be asserted that each color has a complement, that all colors go in pairs, although the colors in the middle of the spectrum have non-spectral colors as their complements. In terms of the four-color theory each primary color has a complement — green is

TABLE I. — TABLE OF COMPLEMENTARY COLORS FOR TWO OBSERVERS

OBSERVER VON KRIES		OBSERVER VON FREY	
Long Light Wave in $\mu\mu$	Complementary Short Wave	Long Light Wave in $\mu\mu$	Complementary Short Light Wave
656.2	492.4	656.2	485.2
626	492.2	626	484.6
612.3	489.6	612.3	483.6
599.5	487.8	599.5	481.8
587.6	484.7	587.6	478.9
579.7	478.7	586.7	478.7
577.6	473.9	577.7	473.9
575.5	469.3	572.8	469.3
572.9	464.8	570.7	464.8
571.1	460.4	569.0	460.4
570.4	440.4	566.3	440.4
570.1	429.5	566.4	429.5

the complement of red, blue of yellow. As each combination of two colors is made up of two simple colors, there is always a second combination of two colors, each complementary to one member of the first pair, which when mixed give gray.

Color Blindness. — The phenomena of color blindness offer much aid to an understanding of color vision. Some three to five per cent of men and a much smaller percentage of women are found by tests to be unable to distinguish red and green. To them reds and greens look exactly alike. When the proper changes in brightness are made, red and green papers look gray and all three may be confused. The fact of confusion has been noted for a long time. The chemist Dalton furnished one of the first instances recorded, and for a long time

the defect was known as Daltonism. It is only recently that fairly general agreement as to the explanation has been reached. Young and Helmholtz and their followers were of the opinion that one might be blind to only one color, one might be red-blind or green-blind, or both. Studies by Von Kries and others who were originally pupils of Helmholtz convinced them, however, that on the whole Hering was right in his statement that when one of a pair of complementary colors could not be seen, the other was also wanting. In brief, the red-blind individual is also green-blind and sees both colors as grays. Still rarer are the cases in which the sufferer sees no colors, but only grays. One other case is rarest of all in which the patient is blue-yellow blind, and can see red and green, but not blue or yellow.

Peripheral Vision. — Closely related to the phenomena of color blindness is the vision on the peripheral retina of the normal eye. It may be said that every eye has in it a red-green blind area, and a totally color blind area. If one will look at any color out of the side of the eye, it will be seen that the colors undergo a marked change. One can see the full range of colors only for twenty or thirty degrees from the fovea; the distance varies with the individual and with the diagonal that is used. Beyond that one can see no reds or greens, but for ten degrees or so farther blues and yellows alone. Beyond that grays only are perceived. The field of vision for colors and for grays extends much farther on the temporal side and below than on the nasal side and above. Of course since light crosses in the eye, the field for color on the retina is larger on the nasal side and

above. Different experiments will not ordinarily show that members of the same pair of colors vanish sharply at the same point, since the point of disappearance depends upon the size of the colored surface, upon the saturation and tone of the color, upon the brightness of the color, and upon its contrast with the background, and it is very difficult to obtain standard stimuli and conditions. When all the colors used have the same values in these respects, the colors vanish by pairs as indicated above.

These facts of color blindness and of peripheral vision indicate that the four primary colors are closely joined in pairs. A study of the colors that remain to the color blind and of the way colors vanish on the periphery of the eye is, then, an important aid to the determination of what are the primary colors. That there are four colors rather than three becomes evident from the fact that first red and green disappear and then yellow and blue.

Negative After-Images. — Two other subordinate phenomena emphasize the opposition between these pairs of colors. These are the negative after-image and contrast. One may obtain a negative after-image if one looks for several seconds at any color and then for a couple of seconds at a neutral surface. The negative after-image is a fainter patch of the complementary color which gradually makes its appearance upon the neutral surface and remains for several seconds. The length of time that it lasts depends upon the intensity of the original color, upon its duration, and the extent of the surface stimulated, and upon the degree of fatigue of the eye. If two primary colors are present

in the inducing stimulus, the complement of each will be present in the after-image. Thus purple gives a yellow-green, orange, a greenish blue after-image. The complete explanation of this phenomenon can best be discussed in connection with the theories of color. We may be content here to regard it as another indication of the fact that complementary colors stand in a very close relation to each other.

Contrast. — The laws of contrast may be stated in terms very similar to those used for the after-image, different from it only in that one relation is spatial, the other temporal. One has been called successive, the other simultaneous contrast or induction. Wherever a color stimulates the retina, a complementary color is induced in the surrounding area. The brightness of the induced color and the size of the halo depend, again, upon the brightness of the color, its size, and upon the similarity in brightness between the color and its background. Contrast colors can be seen most easily if a colored light and a white light are admitted to a dark room and a rod casts a gray shadow on the colored surface. The shadow will appear in the complement of the color. Thus shadows on the grass are purple, those on the snow in yellow sunshine are blue, etc. A gray strip of paper on a colored surface also takes on a color complementary to the paper, but it is not so easily seen by the beginner. If one will cover the entire surface with tissue paper, the contrast color comes out clearly. In general, the rule holds that the less definite the contour between the inducing and the induced color, the more definite the contrast. The

individual has become so accustomed to seeing contrast colors that he forms the habit of allowing for them and sees the objects in the colors that they would have were they alone. He has learned that a gray strip of paper looks red on a green background and sees the gray that is known to be the real color of the paper in spite of its appearance. The tissue paper makes it difficult to be sure that the gray strip is really a separate object on a colored surface, the habitual interpretation is not applied, and the contrast color that is really present on the retina is seen.

Summary of Facts of the Chromatic Series. — Of the pure spectral colors we may assert that all are combined from four primary colors, — red, green, yellow and blue — and that these four colors are paired in most of their activities, red with green, and yellow with blue. Each when mixed with its complement gives gray. In color blindness and on the peripheral retina, red and green, yellow and blue, disappear together. When one of these colors stimulates the retina, its complement appears in the after-image, and the complement also irradiates from its surface, giving the contrast color.

The Achromatic Series. — Fewer statements can be made concerning the brightness series. Unlike the spectral series, there is no break in the series of grays, — one may pass from black to white by a regular series of gradations. Primarily the shade of gray is determined by the intensity of the external stimulation. In this, as in colors, contrast plays an important part. A gray is lighter on a black surface than it is against a white surface. Similarly, the previous stimulation of the

retina plays an important part in determining the apparent brightness. When one has been in a bright light, grays seem darker; when one comes from a darkened room they seem at first brighter than normal. This is related to the negative after-image if the preceding stimulus is comparatively brief. The brightnesses have the same general law of mixture as do colors. Mixtures of grays give an intermediate gray.

One fact that has attracted considerable attention is that the grays, while very complex in their physical stimulus, should nevertheless give a perfectly simple series of sensations. One can obtain gray, as was stated above, only by the mixture of complementary colors. How the combinations of simple rays produce white has been a point in dispute between the three-color and the four-color theories. Helmholtz held that the three primary colors combine to produce white, and that all three must be present if white is to be seen. Hering, on the contrary, insisted that there was a separate organ and separate processes for white, that all lights stimulated this organ, and that complementary colors gave white simply because the colored effects neutralized each other and gave the white which was always present a chance to be seen. Color blindness shows that the assumption of Helmholtz must be incorrect in this respect. Were white a compound of three colors, the individual, color blind to green, when his eye is stimulated by sunlight, should see the remaining colors of the spectrum, red and blue, combined in purple, instead of the gray that he really does see. There is every evidence that the brightnesses correspond to

the excitation of an independent organ. It is not a compound produced by the excitation of the organs of primary colors.

The Duplicity Theory. — One discovery of recent years is that there is a different organ active in seeing faint lights, from that involved in ordinary daylight. While the organ for brightness is usually some substance in the cones, the rods are used in seeing faint lights. The most striking evidence for this is that after long adaptation the retina becomes much more sensitive to faint lights, from two thousand to eight thousand times as sensitive after an hour in a dark room. This increased sensitiveness does not affect the fovea, where, as will be remembered, there are only cones, but only the periphery, where there are rods. This can be proven if one will look at a faint star first directly and then look to one side so that the star may be seen with the periphery of the retina. It looks brighter on the periphery. Stars that cannot be seen with the fovea may be seen when looked at indirectly. This is even more easily demonstrated if one will use a somewhat larger surface. At night a faintly illuminated patch of gray paper can readily be seen out of the side of the eye when it is invisible in direct vision. The increased sensitiveness in the rods is ascribed to the presence of visual purple, which is found only in them, and which, while lacking in daylight, is accumulated after a long period in the dark.

The Purkinje Phenomenon. — Further evidence for this independent rod vision comes out in connection with the third series of phenomena, the variation in color with

diminution in the intensity of a single wave length of light. As was said, the spectral colors tend towards black as the intensity is diminished, and all lose their colors before the light disappears. All lights of low intensity appear colorless. The point at which the colors disappear varies for the different wave lengths. The reds on the whole vanish first as the light is diminished in intensity, while the short wave lengths retain their color at a lower intensity. If a mixture of yellow and red (orange) be gradually reduced in intensity, the red will disappear first, leaving only the yellow component. The orange changes to yellow as the light is diminished. More important is the fact that the brightness of the different parts of the spectrum is differently affected by reducing the light. The long wave lengths are relatively bright in ordinary daylight and the short wave lengths in the twilight. If one compare the brightness of a bit of blue paper and a bit of red paper in daylight and the red be brighter but nearly equal to the blue, and then compare the same bits in a dark room, it is found that the blue will be decidedly brighter. This change in relative brightness goes on gradually and is marked when the absolute brightness is so low that no colors are seen. This change in the relative brightness of colors, known as Purkinje's phenomenon, is also regarded as characteristic of rod vision. It again is not observed on the fovea where the rods are lacking and cannot be detected in daylight on the periphery of the retina where the colors are not seen but where cones are present. It is a phenomenon peculiar to the rods. It may be phrased in the statement that

the rods are relatively highly susceptible to stimulation by the short wave lengths, the cones by the long wave lengths. All of this seems to indicate that there are two distinct organs involved in seeing brightnesses, the

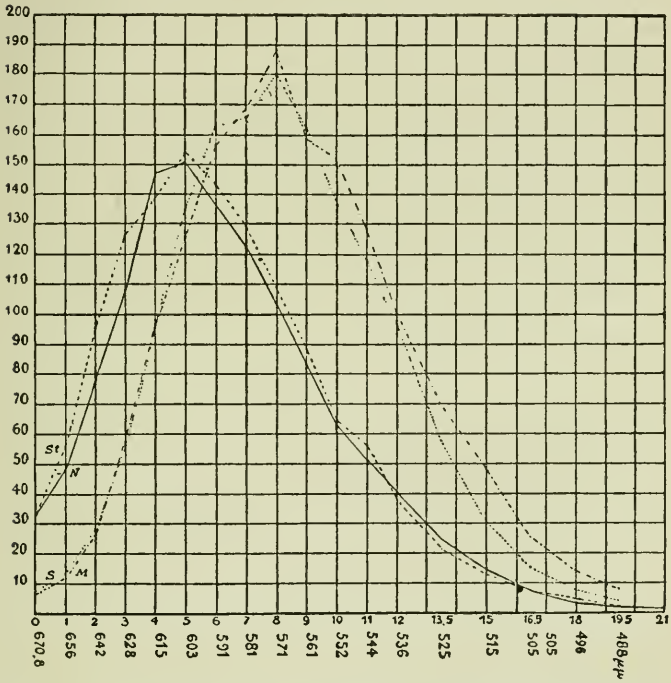

FIG. 45. — Chart showing relative brightness of red light in the spectrum of gas light for two protanopes, *S* and *M*, and for two deuteranopes, *St* and *N*. (From von Kries.)

cones and the rods. A brightness or gray seen with the rods cannot be distinguished from a gray of the same brightness seen with the cones. The only difference is to be found in the relative susceptibility of the two

organs to different lengths of light waves, and in the possibility of greatly increasing the sensitivity of the rods by adapting them to darkness.

The Different Forms of Color Blindness. — The distinction drawn between daylight and twilight vision, or cone vision and rod vision, has proved very fruitful in the interpretation of certain facts of color blindness. In the long controversy between Hering and Helmholtz a standing point of discussion was as to whether there was ever blindness to red without also blindness to green. Hering insisted that blindness to one was always accompanied by blindness to the other. Helmholtz regarded red and green as independent colors and asserted that one might be blind to either alone. Observations seemed ambiguous. Most cases lacked both colors, but occasionally careful examination indicated that one color would be seen more clearly than the other. When the twilight or rod vision was discovered, it was soon found that in the eye of the totally color blind only the rods were active. The patient could see much better in twilight than in ordinary daylight, the relative brightness of spectral waves was the same as that of the normal individual in twilight, and it was shown in a number of cases that he was totally blind in the fovea, where, as has been said, there are no rods. In certain cases the blindness in the fovea was not noticed, but von Kries argues that this was probably due to the difficulty in making observations. Not all would agree that every case of color blindness is due to lack of function of the cones, but certainly many are.

In the application of this discovery to the cases of

partial color blindness, measurement of the brightness values of a number of individuals indicated that the difference between the two types, called by Helmholtz the red blind and the green blind, could be traced to the dominance of twilight brightness values, or to the dominance of daylight values. Both types were defective in both red and green, but as the red blind saw the spectrum,

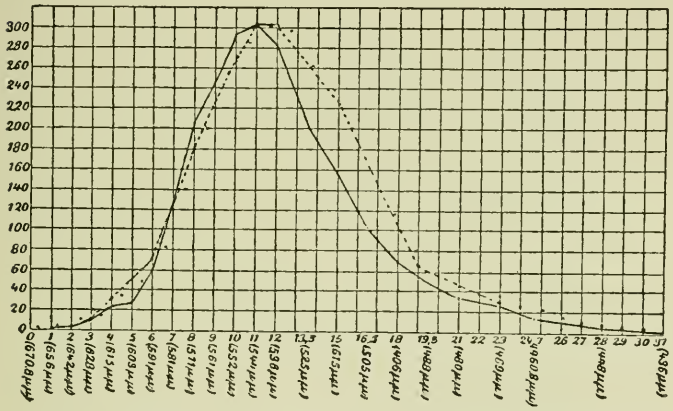

FIG. 46. — Brightness of prismatic spectrum of gas light for total color blind ----, and for twilight vision of normal eye ——. Comparison with Fig. 45 shows that both have the same value as the protanope. (From von Kries.)

the long wave lengths were much darker and so the reds were not noticed. For the other type the long wave lengths were brighter and they were more likely to see the reds than the greens. To avoid the ambiguities of the older terms von Kries has suggested that those individuals who see the spectrum in the relative brightness values of normal individuals in daylight be called deuteranope, those who see it in twilight values shall be called protanope. The brightness values are the

same for the protanope, for the totally color blind and for the twilight vision of the normal eye, and also for the deuteranopes, the normal eye in daylight, and the periphery of the normal eye, as may be seen from the accompanying charts from von Kries. All this argues for two kinds of brightness vision, one by the cones, the other by the rods. While the actual sensations of gray given by the two are not to be distinguished, the secondary characteristics are markedly different.

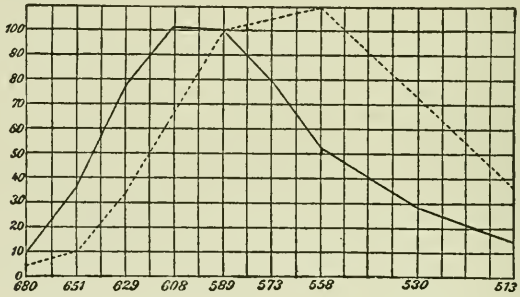

FIG. 47. — Brightness of the gas light spectrum for the periphery of the normal eye ——, and for protanope - - - -. (From von Kries.)

Temporal Phenomena in Vision. — The characteristics of a color depend in many ways upon the duration of the color stimulus. Stimuli do not produce their maximum effect at once nor does the color cease at once with the excitation. There is always a rise to full effect and a gradual disappearance. The course, as has been shown by Miss Bills, is different for each of the colors, both for the period required to attain its maximum, and for the period of decline. The curve varies for each color and for the different intensities of the color. At the lowest intensity used, the order was yellow, red,

green, and blue; for the medium intensity it was yellow, green, blue, red; and for the highest intensity, yellow, red, green, with blue undetermined.[1] These results were obtained in the dark. They may be different for daylight conditions. When the sensation reaches its maximum, it begins at once to diminish in intensity, at first rapidly, and then very gradually until all colors disappear. This gradual loss of color can be easily demonstrated if one will but gaze fixedly at a small square of color. The disappearance of the color of the glass when colored glasses are worn illustrates the same phenomenon. Black and white also show the same tendency. The rate of adaptation varies with the color, so that one component after another may vanish.

After the stimulus is removed, the excitation continues for a moment to be of the same quality as the original, and then gradually dies out. This persistence is called the positive after-image. The dying out corresponds to the period of rise of stimulation. Both may be regarded, and are regarded in all theories, as an expression of the inertia of the color processes. They require time to start and to stop. For a fraction of a second the color or gray persists in approximately full brightness. It is this fact that makes possible the mixture of colors on rotating disks. The excitation of one color persists during the excitation of the retina by the other. For practical purposes the effect is the same as if both lights were active at the same time, and the brightness effect produced is the average of all the lights that are stimulating the eye during the period. If the

[1] Psychological Review, vol. xxii, pp. 126 f.

rotation is less rapid, one obtains a rapid fluctuation in brightness, the flicker. Of practical importance is the fact that the flicker disappears at a less rapid rate of rotation if the brightness of the colors is the same than if they are different. This flicker effect has been taken advantage of in the measurement of the brightness of different colors, a problem that makes difficulties for ordinary photometric methods.

Aside from this positive after-image, if one gives but a single stimulus of relatively short duration, it will be noticed that there are at least two other images succeeding the first. After a momentary dark period there comes a complementary after-image, usually with an added slightly bluish hue. After another dark interval, an image of the same color as the first and usually fainter appears, to be followed by another dark period. Including the dark periods which look like black it is possible under favorable conditions to see six different images following a colored sector on a slowly rotating disk. These images are an expression of the fact that the retina responds rhythmically, that when a retinal excitation is started it rises and falls in its excitation in a regular order. The second of the images mentioned above is assumed to be due to the delayed excitation of the rods, the third to a renewal of the excitation of the brightness organ of the cones.

Interesting also is the fact that it is possible to excite colors as an after-effect of brightness. If one will look for half a second or so at the setting sun and then for a time watch the after-image as projected against a neutral surface, one will observe a slow succession of colors

and grays that will last for several minutes. Helmholtz gave the order as white, red, green, red, blue, with the eyes open. One notes in this, too, that the color of an image depends upon the character of the background. It will have a different color with the eyes open and with the eyes closed. When the eyes were closed, Helmholtz

Fig. 48. — Benham disk.

found the order to be blue, green, yellow. It will also be noticed when a black and white disk is revolving slowly that a series of faint colors seems to follow the edge of the black sector. Similar, too, in explanation is the color produced when a white disk with concentric rings of black is rotated. If a disk similar to that in Figure 48 is rotated slowly, the inner ring appears purplish, the outer greenish. The explanation of all these

phenomena is somewhat uncertain, but seems to fit best with the assumption of Helmholtz that in some way the color processes are excited by the black and white and that the different colors die out at different rates and so one color will predominate at one time, another at another.

The Spatial Phenomena of Vision. — Just as the visual excitation is not limited to the actual duration of the stimulus, its influence is also not limited to the area stimulated, but extends about it in all directions to varying extents. A series of facts can be adduced to demonstrate this.

1. Bright colors always look larger than dark ones. A white square on a black ground always looks larger than a black square on a white ground. In each case the white stimulus spreads at the expense of the black. Still more striking is the apparent increase in the size of the filament of the electric light when it glows as compared with its size when cold.

2. A number of small surfaces of two or more colors when in juxtaposition fuse into a color identical with that given by the same colors when mixed by rotation. Each color extends beyond the area stimulated, and these extensions overlap to produce a continuous color of the average hue and brightness of all. The overlapping in space is similar to the overlapping in time in mixtures produced by rotating disks. In many fabrics it will be noticed that the dominant color seen at a distance is a mixture of a number of threads of different colors.

3. There is a spatial extent of colors that is too small

to be observed, just as there is a temporal and intensive limen. Colored objects at a distance lose their color, and the minimum size varies with the color. The colors disappear before the brightness. Several bits of color, each too small to be seen alone, give color when near each other. This may be explained by the extension of the stimulus on each small surface to the others about it until the mutual overlapping increases the stimulus of each surface to the point where it may be seen.

4. In large degree, size, duration, and intensity are interchangeable. More intense lights seem larger, seem to last longer, and, *vice versa*, within limits larger surfaces and longer exposures seem to give more intense stimulations.

These various phenomena are to be explained by the spread of the effects of the excitation in the retina, either by a spread of the chemical effects from one unit to another, or by a spread of nervous impulse from the cones or rods stimulated to neighboring ones through the connecting neurones just inside the layer of rods and cones. (See p. 112.) Contrast is due to a similar phenomenon, but has been described above, and the explanation may best be left to the discussion of the various theories, as the induction of a complementary color introduces a new principle.

The Helmholtz Theory. — A brief statement of the more important theoretical explanations of color may serve as a review of the facts. The first of the modern theories was formulated by Thomas Young, an English physicist, and expanded by Helmholtz. It assumes

that there are three separate organs in the retina, that one of these is affected most strongly by red, another by green, and a third by blue or indigo. When all three are excited at once, white is produced. Red and green when stimulated together give rise to yellow. All the other colors are produced by the mixture of the effects of two or all three of the organs. After-images are due to the fatigue of some of the organs and the response of those remaining when white light falls upon the retina. Contrast is an illusion of judgment. The facts are out of harmony with the theory on all but one point. 1. Yellow cannot be a compound color, since yellow may be seen where both its assumed components are lacking, on the periphery of the retina and by the color blind. 2. The same objections hold against regarding white as a compound. It, too, can be seen where none of its components is present. 3. The explanation of after-images falls with the abandonment of the theory that white is a compound color. 4. Contrast is not an illusion of judgment, as it is most easily noticed where one is not aware that the inducing color is present. The only possible remnant of the Helmholtz theory is its explanation of color mixing, and the colors that it chooses as primary do not meet any of the physiological tests.

The Hering Theory. — The Hering theory asserts that there are two pairs of primary colors with the elements in each pair opposed, and an independent brightness organ. The theory assumes that each pair of colors is produced by antagonistic changes in the same organ. One organ gives rise to red and green, a second to blue

and to yellow, and a third to the brightnesses, black and white. The antagonistic processes are said to be anabolism and catabolism, the upbuilding of the organ and its deterioration. Green, blue, and black induce anabolism, the others catabolism. Complementariness is explained by the fact that members of the same pair of colors tend to induce opposed processes in the same degree and so produce no effect. When the tendency of green to produce anabolism and of red to cause catabolism are equally strong, no change in the organ results. Since all wave lengths stimulate the brightness organ, gray is seen, and seen alone, when the colors cancel each other. Color blindness is due to an absence of one or more of the organs. The red-green organ is most frequently lacking. This follows from the fact that red-green blindness is most frequent and also that red and green are least widely distributed on the retina. In total color blindness the yellow-blue organ is lacking also, the black-white organ alone is present. Positive after-images are explained as due to a continued action of the organ after the stimulus has ceased. In the negative after-image anabolism is followed by catabolism since the excess material accumulated by the retinal excitation tends to disappear as the light ceases to act and the tissues return to their normal balance. Similarly, catabolism is followed by anabolism as the tissues are restored to their normal balanced state. Contrast is due to one process inducing its opposite in contiguous areas. Excessive anabolism in a stimulated area is at the expense of the nourishment of the other adjoining areas, and catabolism results there.

Criticism of the Hering Theory. — The most important objection to the Hering theory is its assumption that the opposed processes are anabolism and catabolism. Nowhere in the bodily structures is anabolism induced by stimulation. If the exact change be left indefinite, be regarded as a reversible chemical process as Müller and von Kries have suggested, nothing would be lost in adequacy of explanation of the phenomena and much is gained in credibility. A second minor objection, made by Müller, is that it is inconsistent to assume that the opposed processes cancel each other in the color organs, while in the black-white organ they give a sensation, the neutral gray of the rested eye. Müller suggests that the retinal processes really cancel each other, so that when there has been no excitation for a long time the retina gives no sensation, but that the cortical cells, the central organ for vision, produce the gray. As evidence for this he cites the fact that the blind, if not blind from birth, always see this gray, and that a spot of gray is seen where even a small area of the retina has been destroyed.

The Ladd-Franklin Theory. — A recent theory of Mrs. Ladd-Franklin gives an explanation of color in terms of evolution. She assumes that primitive vision in animals is rod vision which gives differences of brightness only. Later cones develop and with them comes the appreciation of colors. Within the cones there is also a development. First appear substances sensitive to blue and yellow alone, then the substance sensitive to yellow divides into two, one sensitive to red and the other to green. Each more evolved organ

may act as a whole to give its original sensation. The cone when stimulated as a whole gives brightness, the red and green acting together give yellow. The color-blind eye is an undeveloped eye. In red-green blindness the yellow substance has not yet subdivided, in total color blindness the cones act only as rods. While very ingenious, its choice of primary colors is open to all of the objections to the Helmholtz theory, and it fails to recognize the differences between rod vision and cone vision as seen in the Purkinje phenomenon or to explain them in an adequate manner.

In the maze of theories certain essentials must not be lost sight of. 1. There are four primary colors, distinguished from the others by the fact that they vanish without change of quality as they are moved outward to the periphery. 2. These four colors are arranged in pairs, red with green, blue with yellow. The pairs cancel when mixed in suitable proportions; one induces the other as an after-image and excites the other on the surrounding areas of the retina. 3. There is an independent brightness which is present in all colors and is seen alone when the colors cancel each other, at low intensities of light, and where the color organs are lacking. Physiologically we must assume an organ for each pair of colors. For this the Hering theory as modified by von Kries is as acceptable as any. That means a single organ for each pair and in each organ opposed chemical processes. The exact nature of the processes must be left undecided. To this must be added the acceptance of a distinction between rods and cones as organs for brightness. They give the

same sensations of brightness, but the rods are more sensitive absolutely and are also relatively more sensitive to the short wave lengths; the cones more sensitive to the long.

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CHAPTER V

SENSATION, AUDITION, TOUCH, ETC. WEBER'S LAW

The auditory sensations stand next to the visual, both in complexity and in importance for behavior and mental life in general. We can approach them from three different sciences and obtain an entirely different set of phenomena in each. Physically, sound is vibration in the air; physiologically it is oscillation of some delicate membrane in the ear; psychologically it is the series of sensations, the material of music and human speech on the one hand, and the series of noises and unorganized sounds on the other. The physical processes consist of longitudinal oscillations that proceed outward concentrically from the vibrating body. These oscillations may be superimposed upon one another, making waves of great varieties of complexity, but always analyzable into their simple elements. The rates that can be heard range from 16 or so to from 30,000 to 50,000 per second.

The Structure of the Ear. — The organ that translates these vibrations in the air into nerve processes is the ear. The ear is composed of three parts: the external ear, consisting of the pinna, commonly called the ear, and the external auditory meatus or tube that runs into the head; the middle ear, an enlarged cavity in the skull

separated from the external by the membrane of the tympanum or drum; and the internal ear, a labyrinthine cavity between the middle ear and the brain where the vibrations are translated into nervous impulses. The external ear needs no description. The outer ear

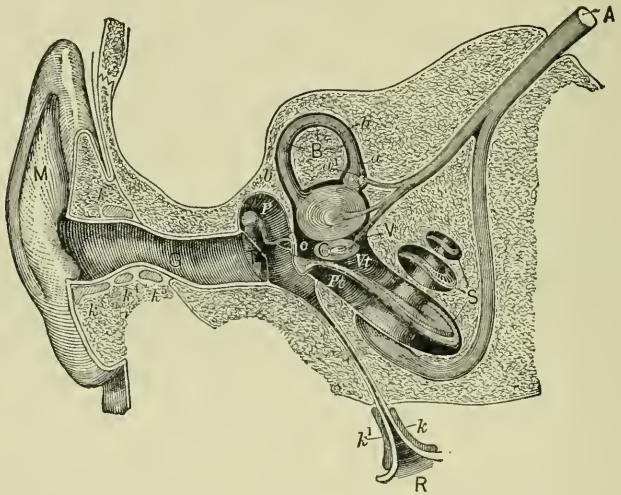

FIG. 49. — Schematic section of the ear; *M* and *G*, external ear; *P*, middle ear with small bones; *S*, cochlea; *B*, semicircular canal; *A*, auditory nerve; *R*, Eustachian tube. To give a sectional view the cochlea is displaced 90°. Its apex should be turned toward the observer. (From Calkins, after Martin-Czermak.)

probably has some influence in collecting the vibrations in the air and turning them into the external meatus. The meatus itself is curved slightly and thus reduces to a minimum the probability of injury to the membrane of the tympanum.

The important structures of the middle ear are the membrane of the drum, three small bones that stretch

across the cavity of the middle ear, and the membrane which with the plate of the last of the bones fills the oval window of the inner ear. The series of bones consist of the malleus, incus, and stapes, named from their

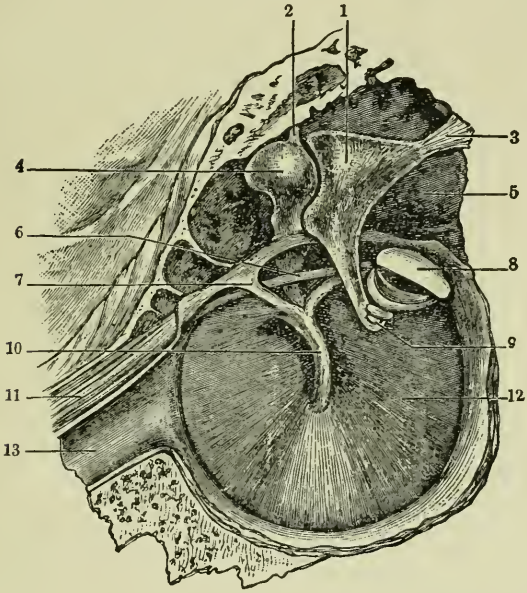

FIG. 50. — Tympanum and small bones seen from within the middle ear. 1, anvil; 2, suspensory ligament of hammer; 4, head of hammer; 7, tendon of tensor tympani; 8, foot-piece of stirrup that fits into the oval window; 10, handle of hammer or manubrium; 11, tensor tympani; 12, membrane of the drum; 13, Eustachian tube.

shapes, which resemble a hammer, anvil, and stirrup, respectively. The handle of the hammer is fastened to the inner surface of the membrane of the tympanum, the head is jointed into the top surface of the anvil, not unlike a large molar tooth in shape, and is hung

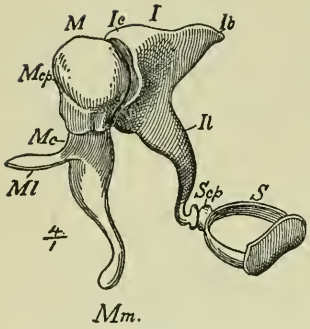

FIG. 51. — The bones of the middle ear. *M*, hammer; *I*, anvil; *S*, stirrup.

by a ligament from the top of the cavity of the middle ear. The stirrup is attached by a delicate cartilage to a process of the anvil, not unlike one of the roots of the tooth. The membranes and the bones swing together on the ligament as a fulcrum. When the air vibrations impinge on the membrane of the drum, it swings inward, carrying the hammer and the other bones with it, and the foot of the stirrup pushes against the lymph of the inner ear, and sets that in vibration also. Two muscles prevent movements strong enough to rupture either membrane. One, the tensor tympani, extends sidewise from a bony canal inside of the tympanum and is inserted in the head of the hammer; the other, the stapedius, extends from a tube in the lower inner wall of the cavity and is inserted by a long ligament in the head of the stirrup near where the anvil is joined to it. The two muscles oppose

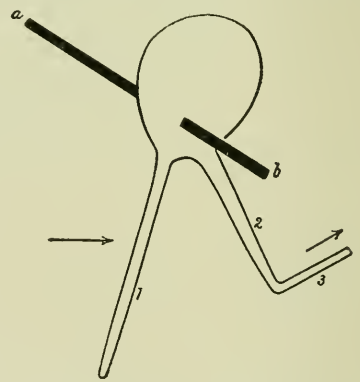

FIG. 52. — Illustrates the way in which the three bones act together as a bent lever. 1, the handle of the hammer; 2, the long process of the anvil; 3, the stirrup; *a–b*, the axis of rotation. (From Howell's "Text-book of Physiology.")

each other. The tensor tympani tends to draw the drum head inward, the stapedius to draw the stirrup foot away from the oval window toward the drum head. When both contract, the entire vibrating mechanism is held firm and prevented from making too violent oscillations.

The membrane of the drum, by virtue of its conical shape, the arrangement of the fibres that compose it, and the weighting on one side only, has no tone of its own, responds to all vibration rates impartially, and so transmits all tones, whatever their pitch, with approximately equal strength. In traversing the middle ear, the amplitude of the waves is decreased and their intensity increased very greatly. This change takes place in two ways. First the area of the oval window is much smaller than the area of the drum, so that the energy is more concentrated. Second, as can be seen in Figure 53, the lever arm formed by the hammer of the handle has a greater effective length than that formed by the process of the anvil to which the stirrup is attached. Sound waves, then, traverse the oscillating mechanism of the middle ear with rate or pitch unchanged but with intensity increased twenty to thirty

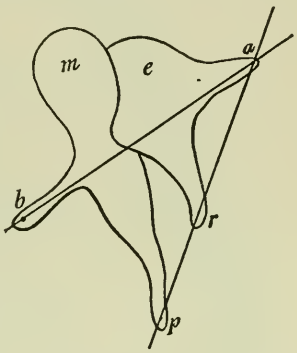

FIG. 53. — To illustrate the lever action of the ear bones. *m*, the hammer; *e*, the anvil; *a*, the short process of the anvil which abuts upon the wall of the middle ear and serves as point of rotation; *a–b*, the power arm; *a–p*, the load arm of the lever.

times and with a considerable diminution in amplitude. An essential mechanism for making possible the vibration of the drum and for protecting it against rupture due

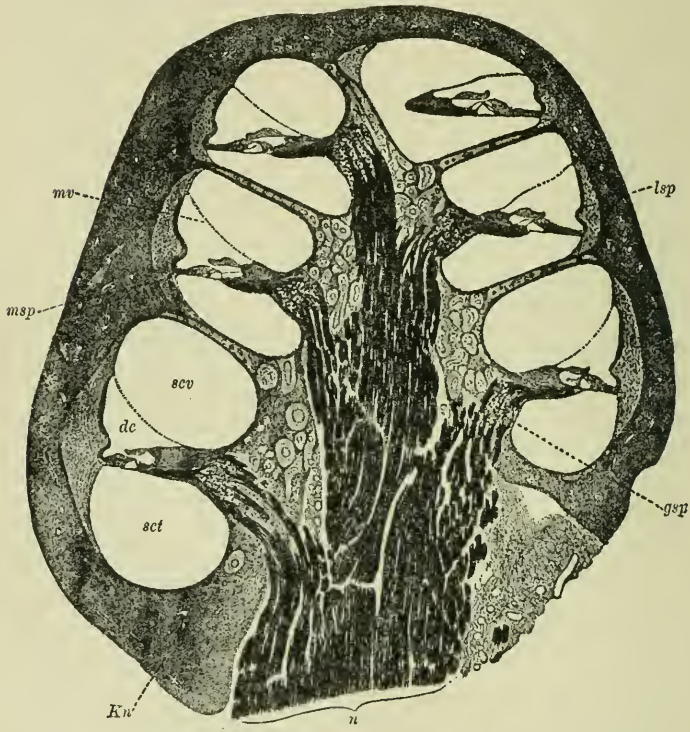

FIG. 54. — Longitudinal section of the cochlea of a cat; *dc*, cochlear duct; *gsp*, spiral ganglion; *msp*, membrana spiralis (basilar membrane); *mv*, Reissner's membrane; *n*, cochlear nerve; *sct*, scala tympani; *scv*, scala vestibuli. (From Huber, after Sobotta.)

to difference in air pressure in the outer air and that within the ear is the opening into the throat provided by the Eustachian tube. This serves to keep the pres-

sure of the air in the middle ear approximately equal to that in the outside world. The act of swallowing opens the tube and permits the interchange of air.

The Cochlea. — The inner ear, or labyrinth, is filled with lymph. It has two openings into the middle ear, both closed by delicate membranes. One we have mentioned as receiving the foot of the stirrup. The joint is made watertight by a membrane. This is the oval window. The other, a little below the oval window, is closed by a simple membrane. From its shape it is called the round window. We may distinguish two parts of the inner ear, the cochlea and the labyrinth proper, — the semicircular canals, utriculus, and sacculus. As the cochlea alone is concerned in hearing, a description of the other structures may be left over. In essentials the cochlea is a tube divided up its middle by a partition of bone and membrane. One side of the partition is closed by the oval window, the other, or lower, by the round window. The tube is wound two and a half times about a central column of bone, the modiolus. The cochlear nerve, the nerve of hearing, enters the centre of the modiolus, and ascends to the top, giving off a spiral band of nerves from the bottom to the top of the cochlea. It enters through the spiral ridge of bone, the lamina spiralis, and ends in close connection with cells tipped with hairs on and about the basilar membrane. This basilar membrane, together with the lamina spiralis, constitutes the dividing partition of the cochlear tube. If one looks at a section of the cochlea, one sees five or six sections of the tube (Fig. 54). In each of these there are three divisions, the cross sections

of canals. The upper one in the figure is called the scala vestibuli, the staircase of the vestibule, since it connects directly with the vestibule and the oval window. A small triangular canal is divided off by the basilar membrane and a delicate membrane above it, Reissner's membrane. This is the cochlear canal. Below the basilar membrane is the scala tympani which connects with the round window. The vibrations of the stirrup are transmitted to the lymph through the oval window, and ascend to the top of the cochlea by the scala vestibuli. At the apex is an opening between the scala vestibuli and the scala tympani, which is supposed to permit the vibrations to pass from one to the other. The delicate membrane of the round window permits the liquid to vibrate as it could not were there but one opening to the cavity filled with liquid. By virtue of these connections, the liquid in the cochlea vibrates at the rate of the sound wave in the air, with greater force but with less amplitude.

The Sensation of Tone. — The problem for the theory of hearing is how the vibrations in this liquid in the cochlea may excite the auditory nerve. To answer this question we must turn to a consideration of the facts of auditory sensation. The qualities of tone run in a single line from low to high. Slow vibrations give low tones, rapid vibrations high tones. The lowest tones that can be heard vary from about twelve to sixteen per second. The upper limit was given by Galton at 50,000, by Preyer at 40,000, Bruner from 22,000 to 43,000 for different individuals, while Edelmann asserts that some individuals can hear 50,000 vibrations.

The lower tones are determined by means of large forks, the upper usually by a whistle with very short barrel, first devised by Galton, of which a new and more accurate model has recently been made by Edelmann. The intermediate tones increase regularly in pitch.

The accuracy with which the pitch of tones may be distinguished varies markedly with the absolute pitch. Tones in the middle range can be discriminated much more easily than very high tones or very low tones. From 64 to 1024 V D,[1] one can distinguish differences as small as to 0.3–0.2 of a vibration. Above or below this, tones must be much more different to be distinguished. At 32 and 2048 V D the addition of 0.4 of a vibration can just be noticed, and for very high and very low tones many vibrations may be added before a difference is noted. One can distinguish tones differing by these amounts and even say which is higher and which lower. On the basis of these experiments by Preyer, Luft [2] and Max Meyer,[3] it has been estimated that one can distinguish approximately 11,000 different pitches.

Within the range of audible tones there seem to be critical points similar in a way to the critical points in the spectrum. In the sound series these critical points are the octaves of the musical scale.

The octave corresponds to the spectrum. As one may say that the ends of the spectrum are more similar than the middle to either end, so double the vibration of any tone gives a note that is more similar to it in one

[1] V D means double or complete vibrations.
[2] Philosophische Studien, 4, 511 ff.
[3] Zeitschr. f. Psychol. u. Phys. d. Sinnesorg. 16, 352 ff.

respect than the intermediate tones. These octaves constitute, for the trained ear at least, regularly recurring units of tone within which again the notes whose vibration rates form a ratio of 2 : 3, 3 : 4, 4 : 5, etc. with the lower note of the octave constitute other marked resting points or definite qualities which may be regarded as distinct from all others. Trained ears are more likely to make a mistake of an octave in the note than to mistake one note for another within the octave. This may possibly be due to musical training, as many other systems of music, the Chinese, *e.g.*, seem not to recognize the same distinctions, but the balance of evidence at present seems to favor the view that the distinction is fundamental.

In recent discussions much has been made of this peculiar relation of the qualities of the notes within the octave. It has been suggested by Meyer, Révész, and others that tones may vary in quality in at least two ways; in musical values which depend upon the position of the note in the octave, and in pitch which is determined by the absolute vibration rate. We shall have occasion to notice this distinction again.

Tone-Color. — Two other differences in the quality of tones may be mentioned. One, that tones of the same pitch from different instruments have a characteristic difference ordinarily spoken of as timbre or tone-color, which depends upon the overtones that are added to the fundamental. Thus in the C of 64 double vibrations from a piano string there are also found the c of 128, the g of 192, the c′ of 256, the e′ of 320, the g′ of 384, the seventh overtone of 448 which

does not correspond exactly with any note in the scale, the c″ of 512, etc. Every multiple of the rate of vibration of the fundamental is represented, theoretically, since they correspond to the nodes in which the sounding body vibrates, and these nodes are formed at each small fraction of the length of the sounding body. The first ten overtones can be readily heard when intensified by resonators. If one will hold down a key on the piano that corresponds to one of the overtones, one can hear that overtone continue to vibrate after the fundamental has been dampened by dropping the key. It is started into vibration by resonance and continues to vibrate for a time after its excitant has stopped. With practice one can hear the overtones separately with the unaided ear. Each instrument has its own arrangement of overtones, and these give it its timbre. The tuning fork has almost none; in the piano they are present in fairly even strength, while in the violin certain of the high ones are emphasized at the expense of the lower. Each of the musical instruments owes its peculiar quality to the number, pitch, and relative strength of its overtones.

Tone and Noise. — The other even more fundamental difference in sounds is that which obtains between tones and noise. The difference is sufficiently familiar to need no description. Physically as well as psychologically two forms of noise are to be distinguished. The more usual is due to a very complex mass of tones that have no simple relation in their vibration rates, and have even been said to be non-pendular in character. Any inharmonious combination of many tones is ac-

cepted as noise. A noise of this kind passes gradually over into tone, as the degree of dissonance is lessened, or the tonal element comes to predominate. If there are any tones that are not reducible to the ordinary pendular or sine form, they may also be present in noise. That complex sounds like the sawing of wood or the rattle on a city street are merely tones in great number and variety without any harmonic relation is probable, since with resonators one can distinguish tonal elements in them. The second type of noise corresponds to a simple vibration too short to produce the full tonal character. If one will cut off a pure tone after only one or two full vibrations have been made, one obtains a sudden noise that lacks the tonal character. This is usually done by passing the tone through a tube that can be opened to permit the sound to pass for only a fraction of a second. When less than two full vibrations reach the ear, the effect is a shock. The full tonal character of the sound is obtained only when sixteen full vibrations are heard. Noise and tone, then, are different only in the time of stimulation or in the arrangement or combination of the elementary waves, not in the character of the waves themselves.

Vowel Qualities. — Much controversy has resulted from the attempts to explain the characteristic differences of the vowels. Helmholtz and König believed that they were due to the presence or absence of overtones. The overtones were emphasized by the resonance of the mouth chamber which is changed in shape by the contraction of certain muscles. This supposition was confirmed by synthetizing vowels, — *i.e.* by put-

ting together simple tones to constitute the fundamental with its overtones. Recently there has been revived by Köhler an old theory of Hermann that vowels were not always due to the presence of overtones of the fundamental note of the tone, but that the characteristic of the vowel was some single note which did not change with the pitch of the fundamental, as would be necessary if it were an overtone. These characteristic notes were called formants by Hermann and were assumed to be developed by the air blown through the mouth cavity, which was given a different form for each vowel. Köhler tested a number of individuals by giving them a series of tones which could be gradually changed and asking them to say when the tone took on a vowel or consonant character. His results indicated that the vowels were about an octave apart through the scale. In order he gives the following tones as corresponding to the tone of letters: $m = 130$, $u = 260$, $o = 520$, $a = 1040$, $e = 2080$, $i = 4100$, $s = 8200$, $f = 17{,}000$, $ch = 34{,}000$. All the values are approximate only and the sounds are the sounds of the German letters. Between the pure vowels are mixed ones. One shades gradually over into the other and both elements can be distinguished. Not only does this theory serve to explain the vowel sounds, but it explains the characteristic differences in the series between the octaves. The notes repeat themselves in the octaves, and the beginning of the repetition is marked by the change from one vowel tone to another. It is suggested that the sensations corresponding to increased vibration rate may be pictured as a spiral, with the same

notes over each other. How far the results of Köhler's experiments are to be accepted is still a question, but it adds one more to the puzzles presented to a theory of tone.

Certain it is that at present the problem of the attributes of tone is in a very confused state. All agree that pitch, noise, and timbre are to be distinguished. But to these, various authorities, Révész, Köhler, and Meyer among them, would add vocality or the characteristic vowel quality, and the tonal quality that is important for music as distinguishing the different qualities within the octave. Köhler asserts that vocality and brightness, together constituting tone body, are distinct from musical quality, although all vary with vibration rate. Révész makes pitch, quality, and vocality distinct, partly on the basis of introspection, partly because he has found pathological cases in which a patient may appreciate one and not the other. Pitch is the quality that increases regularly with rate of vibration, musical quality undergoes a change through the octave but comes back to the identical quality an octave higher, while the vowel quality depends upon the absolute pitch, and its characteristic points of change are at the different octaves. How far these distinctions may prove themselves is hardly a matter even for speculation at present.

Tonal Fusion. — Of the various phenomena that were mentioned in connection with vision, some are also to be noticed in sound. The phenomenon of mixture of colors is replaced by fusion of tones. The two are not easily comparable, since the result of the combination

of tones is so completely dependent upon the position of the notes within the octave and is so complicated by the admixture of feelings. In the first place, each note in a fusion can with a little practice be heard separately, there is no fusion that gives an intermediate tone as in color, and no cancellation, no phenomenon allied to complementariness. In the second place there is a peculiar added quality, the degree of fusion of the whole that depends upon the ratio of vibration rates of the two tones; the smaller the numbers that represent the ratios, the closer the fusion. The best fusion is furnished by the octave, whose components give a vibration rate of 1 : 2, the fifth, 2 : 3, and decreases with the ratios represented by larger numbers as the second, 8 : 9; the seventh, 8 : 15, etc. This relation holds at least approximately, although critics have insisted that the degree of fusion in certain combinations does not correspond accurately to the smallness of the numbers that express the ratio of vibration rates. Thirdly, there is availability of the combinations for musical effects, depending partly upon degree of fusion, more upon the training of the hearer. This dependence upon training is shown by the difference in what is regarded as pleasant between occidental and oriental music and in the gradual change in the accepted intervals in western music. The tritone, the fourth, and the fifth, the accepted intervals of the Greeks, have gradually given way to the thirds and sixths, and now we see seconds and sevenths admitted to music under certain circumstances. It is the feeling tone, as well as the physical combinations, that determines the effect.

Beats. — An effect of combinations that is purely sensational is found in the beat. If two tones of approximately the same pitch are sounded together, there is heard an alternate increase and decrease of the tone which comes as many times a second as the difference in the number of vibrations per second of the component tones. Physically this is due to the fact that the component tones will be alternately in the same phase and in opposite phases. When they are in the same phase, the resultant will be the sum, when in opposite phases, the difference, of the two tendencies to vibrate. When these alternations come some distance apart, they are heard as distinct swellings and diminutions; when closer together, merely as a roughness of the tone. For the theory it is interesting to note that the beats seem to be carried by neither of the tones themselves, but by a tone intermediate between the tones that produce the beats. This we must come back to later.

After-sensations. — Like colors, tones have after-sensations, but only positive ones. It requires some time for a tone to reach its maximum, and also it persists some little time after the physical excitation ceases. The ear is much more rapid in its adaptations than the eye, however; it has much less inertia. According to Mayer separate tones can be heard if they are repeated as frequently as 27 per second for notes of 64 V D and 204 times per second for a note of 1024. There are also intermittent after-sensations of tones, but they are not so often noticed as after-images. Urbantschisch reports that single primary after-tones may last from one to ten seconds. The intermittent after-images may

follow each other at irregular intervals for one to two minutes. Each after-sensation will last from 10 to 15 seconds at intervals of from 10 to 20 seconds. Usually these intermittent tones are of the same pitch as the objective tone, but some may be higher or lower. They are fainter than the original and usually fluctuate in intensity.

Corresponding to color blindness are rare cases of what are called tone islands, — the patients are deaf to limited portions of the scale and can hear notes above and below. More frequent are individuals whose range of audition is shortened above and below, and it is a fairly general rule that the upper notes gradually cease to be heard with increased age.

Combination Tones. — An interesting phenomenon of hearing is furnished by combination tones. When two notes are sounded, one frequently hears, in addition to the notes themselves, tones that correspond to the difference between their vibration rates or to the sum of their vibration rates. Thus if the tones c and e of 128 and 160 be sounded together, one will hear a note corresponding to the difference in their vibration rates, 32. One can also hear a second difference tone whose rate is the difference in rate between the higher and twice the lower ($2l - h$) of 96 and a third tone ($3l - 2h$) of 64. Some authorities report that they hear fourth and fifth difference tones named on the analogy of the last. The striking aspect of these tones is that they are entirely subjective; they cannot be heard more clearly by means of resonators than by the unaided ear, and all other means of demonstrating their objective existence

fail. They must apparently be accounted for by the physiological or psychological theory of hearing. Another combination tone is the summation tone. This is a note that corresponds to the sum of the vibration rates of the component tones. It is not so easy to hear as the difference tones, and it is more difficult to obtain pure conditions for it, as in many cases it will correspond to an overtone or to a difference tone between the overtones. The summation tones are probably of subjective origin, but no satisfactory explanation has been given of how they originate.

Theories of Hearing. — The physiological theory can be discussed only in connection with the structures about the endings of the auditory nerve in the cochlea. As was said, the auditory nerve enters the centre of the modiolus about which the cochlear canal is wound, and the sheet of fibres extends through the lamina spiralis to end in the neighborhood of hair cells on the basilar membrane. The structures here are somewhat complicated, but the theories have made no use of most of the complications. The membrane that helps to divide the cochlea into two canals consists in large part of transverse fibres. These for Helmholtz constitute the essential part of the basilar membrane. Below them is a layer of connective tissue which is thicker than the layer of fibres. On the basilar membrane are found several peculiar structures. The most striking of these are the rods of Corti. These consist of two rows of delicate structures curved and fitted together at the top to form a clearly defined arch. One row leans away from the central column, the other towards

it, and the two seem to be jointed together at the top. They leave an opening between them, the canal of Corti. These rods are not continuous longitudinally and are considerably less numerous than the fibres of the basilar membrane. On the inner side of the arch is one layer of cells with a tuft of hair at the top; on the outer side are four or five layers, with similar tufts that extend through a membrane, Kölliker's membrane, to the lymph of the cochlear canal. Covering the outer portion of the basilar membrane are relatively thick epithelial cells. On the inner side, extending out from and well above the lamina spiralis is a delicate membrane, the tectorial membrane, which hangs free in the liquid above the entire width of the differentiated mechanisms. These can all be made out in Figure 55.

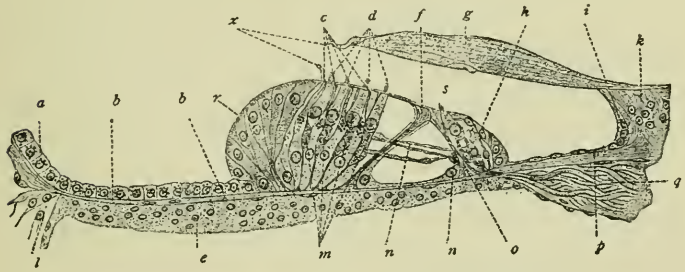

FIG. 55. — Organ of Corti. *b*, basilar membrane; *d*, outer auditory or hair cells; *s*, inner auditory cell; *f*, top of outer rod of Corti, forming one side of the arch of Corti; *o*, inner pillar cell; *g*, tectorial membrane; *q*, nerve fibres; *n*, nerve fibres extending across the canal of Corti. (From Huber after Retzius.)

On first sight one would think that the rods of Corti must be the essential organ of hearing. They are so highly developed and delicate that a teleologist would insist that they must have some specific function.

The most fully developed theory is that of Helmholtz. In essentials it assumes that there must be in the ear resonators tuned to each tone heard. An analogy can be drawn with the piano strings which vibrate in sympathy with the tones that are present in the outer air. If one speaks in a room with a piano, the tones of the voice will be heard sounding after the voice has ceased. If one will hold down a key and sing, the corresponding note will be distinctly heard to respond in sympathetic vibration. Helmholtz believed that there must be resonators in the ear which respond in the same way to the vibration for which they are tuned. His first idea was that the arches of Corti must be these organs. When they were counted, however, it was found that there were only 3000 of them, while it was known that some 11,000 tones could be heard. Helmholtz then turned for his resonators to the fibres of the basilar membrane. These are sufficiently numerous (18,000–24,000) to provide a resonator for each tone that can be heard. They also show some difference in length, — at the upper end of the cochlea they are approximately 0.48 mm. long, at the lower end about 0.04. This is not difference enough to account for the difference in pitch that they are supposed to show, but Helmholtz assumed that they were differently loaded and tuned by that means for the different tones.

In the completed theory, then, it was assumed that there were in the basilar membrane fibres which were tuned to each note that could be heard. The various complex vibrations were impressed upon the liquid of the inner ear by the oscillations of the stirrup, and these

were analyzed into their parts by the fibres. In a piano tone, or other note rich in overtones, a separate fibre was set into vibration by the fundamental and by each of the overtones; in a chord each component similarly aroused a different fibre or group of fibres and each was sent to the centres by a separate nerve. The vibrations of these fibres served in some way not made very clear to stimulate the nerve fibres between the hair cells. The vibration of the fibres was dampened by the tectorial membrane, which was assumed to drop down upon them when the sound ceased. Noises were at first assigned to the vestibular structures, but when these were discovered to have another function, they too were regarded as due to excitations of many fibres in the basilar membrane. Indirect evidence was found to support the theory in the fact that in cases of deafness to part of the scale, parts of the basilar membrane were likely to be diseased. Von Bezold has found that patients who have the so-called tone islands, parts of the scale that they cannot hear, also are found after death to have lesions in the corresponding part of the basilar membrane. In the aged the lower part of the basilar membrane is often in a pathological condition, and they fail to hear high tones.

Criticism of Helmholtz's Theory. — The theory is adapted to explain a number of the facts of hearing. Beats may be regarded as due to an overlapping of the vibrating portions of the membrane, and thus as giving rise to an interference phenomenon in the intermediate fibres. On this assumption each tone would cause a ribbon of several fibres to vibrate instead of a single

fibre as Helmholtz first asserted. When they were near together, the outer edges of the two ribbons would have common fibres. These would tend to vibrate with the rates of both notes, and the interference of the two movements would cause the beats. This view receives support from the fact mentioned earlier that it is a note intermediate between the other two that beats rather than either of the component tones. It is the intermediate fibres that are vibrating at two different rates and consequently carry the beats. When the vibrating ribbons are sufficiently far apart there are no interferences and so no beats.

An explanation of consonance is furnished by the Helmholtz theory on the basis of beats. The notes that give the most perfect fusion are themselves far enough apart not to beat and also give rise to no beats between their overtones. Thus the fifth with a ratio of vibrations of 2 : 3 would have as overtones of the first components 4, 6, 8, 10, etc., and as overtones of the second component 6, 9, 12, etc. Of the first four overtones only the 8 and 9, 9 and 10 would be near enough to beat or be dissonant, and two of the first four would be identical, the others no less consonant than the fundamentals themselves. On the other hand, the major seventh, with a ratio of 8 : 15, while giving no beats between the fundamentals, would have beats between most of the overtones. The fundamental of the higher, 15, would beat with the first overtone of the second, 16, the third overtone of the lower beats with the first of the higher, and in general there are many beating overtones and no identical ones below the eighth of one and the fifteenth of

the other. In general, then, dissonant chords may have beats either between the fundamentals or the overtones, while consonant chords have few beats if any between either fundamentals or overtones. This mechanical theory has been questioned, as will be seen in Chapter VIII.

The explanation of difference tones is not so satisfactory. Helmholtz at first thought they might be beat tones, misled by the fact that there would be as many beats per second as the vibrations per second of the difference tones. This was given up when it was seen that the beats could not stimulate the corresponding fibre in the basilar membrane. His final explanation was that they must be produced in the middle ear. He demonstrated by a differential equation that a membrane loaded on one side alone when excited simultaneously by two rates of vibration should produce a third vibration that corresponds in its rate to the difference between the rates of the two components, but he did not point out the physical correlates of his mathematical values.

On the whole the Helmholtz theory is most detailed of any, it accounts for more facts than the others, and receives more incidental support. Its weakness is a conflict with the anatomical findings. The basilar membrane does not consist of a series of delicate fibres hanging relatively free and separated from each other. Instead, the fibres are embedded in a mass of tissue on both sides thicker than the fibres themselves. Ayers tested the possibility of the basilar membrane's vibrating to tones on the ear of a criminal who had just

been executed, and found that even with this perfectly fresh material and the most favorable conditions no vibration in the basilar membrane could be detected.

A recent suggestion of Shambaugh[1] would remedy the difficulties that arise from the use of the basilar membrane as the vibrating mechanism and at the same time retain the theoretical advantages of the resonator theory. This consists primarily in substituting the tectorial membrane for the basilar membrane as the resonating organ. According to Shambaugh, the tectorial membrane is a very delicate sheet of fibres, attached at both ends and penetrated by the delicate hairs of the hair cells. He also asserted that in his preparations the fibres at the top were ' several hundred times as long as those at the bottom,' affording a sufficient range to supply resonators for the different pitches that can be heard. All of the objections to the Helmholtz theory would be removed and all of its advantages retained if these statements concerning the anatomical structures should be confirmed.

Unfortunately for the theory, Hardesty[2] repeated the observations of Shambaugh on the same kind of material, the cochleæ of young pigs and pig embryos, and is quite as fully convinced that the old descriptions of the tectorial membrane are in the main correct. It is attached at but one end, is well above the hairs, and comes into contact with them only when vibrating, and is only about three times as wide at the top as at the base

[1] Shambaugh, Minute Anatomy of the Structures of the Cochlea, Amer. Journ. of Anatomy, vol. 7, p. 245.

[2] Hardesty, On the Nature of the Tectorial Membrane, etc., Amer. Journ. of Anatomy, vol. 8, p. 109.

of the cochlea. The fact that it is attached at one end only would prevent it from vibrating through resonance; its tissue does not show a sufficiently fibrous character, and the width is not sufficiently different to give support to the resonance theory. Who is right as to the anatomical structures, new work must determine.

Telephone Theories. — Other theories all abandon the resonator principle, assuming instead that some structure in the cochlea must vibrate as a whole and the analysis of the separate tones be made by the cortical centres. Hensen and Rutherford have assumed that the basilar membrane, acting much like the plate of a telephone, transmits the complex notes to the cortex where analysis takes place. Max Meyer has a somewhat similar theory. His assumption is that the intensity of the tone is determined by the distance the vibration extends inward from the oval window, while the quality is determined by the rate of vibration of the membrane as a whole. Hardesty, as a result of his studies mentioned above, has abandoned the basilar membrane as the vibrating mechanism and assumes with Shambaugh that the tectorial membrane is the receiving organ. Hardesty assumes that the vibrations of the liquid are taken up by the tectorial membrane and communicated to the hair cells and thence carried to the brain, where, as in the other theories of this type, analysis takes place. The difficulty with this whole group of theories lies in the assumption that differences in vibration rate so slight as one in ten thousand should be appreciated by the cortex, while the most delicate

appreciation of differences in intensities is one in a hundred. The difference in intensity that can be appreciated by the ear is only one in five. On teleological grounds, which of course have little weight, it seems inexplicable that the extension of the auditory nerve over such a wide area with relatively complicated end organs should have no particular function.

It can be seen that in spite of the ingenuity and hard work that has been devoted to the problem, a satisfactory theory of hearing is yet to be developed. The Helmholtz theory has the advantage of all the others in the number of facts that it explains and the detailed nature of its explanation; it suffers from the improbability of its demand that the fibres of the basilar membrane vibrate separately. On the other hand, the theories that give a plausible explanation of the way the anatomical structures may act make large demands on our ability to distinguish differences between vibration rates.

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TACTUAL SENSATIONS

Cutaneous Sensations. — The sensations from the skin are simplest of all and their organs are most accessible, but only in the present generation have the more im-

portant facts concerning them been discovered. The same distinctions between physical stimulus, physiological processes, and sensations that we have been compelled to make in the other senses are to be drawn here. The adequate stimuli for the skin are mechanical and thermal. But while the stimuli vary only in intensity, different sense organs are affected by different intensities, and corresponding differences in sensation result. This is most marked in the temperature sense. The physicist assures us that cold is nothing positive, but merely a reduction in the amount of heat. Nevertheless when the temperature is reduced below about 30° C. a sense organ is excited which gives rise to the sensation of cold, and this sensation increases as the temperature is lowered. Above 30° there is a similar increase in the stimulation of the organ of warmth with increasing temperature. Similarly, slight mechanical stimuli excite sensations of pressure and intense ones sensations of pain. We then have four distinct sense qualities, while there are but two kinds of physical stimulus. More clearly than in any other organ can the sense qualities be shown to depend upon the organ stimulated.

The discovery of the distribution of the organs, and with that the settlement of most of the problems of cutaneous sensibility, is a matter of comparatively recent date. It came first in the temperature senses. At approximately the same time and altogether independently of each other three investigators, Blix, a Scandinavian (1882), Goldscheider, a German, and Donaldson, an American (both 1885), found that the skin was sensitive to temperature only in relatively isolated spots rather than

all over, as had been earlier supposed. The skin was carefully tested point by point with a cooled or heated metal point, and it was found that at certain points irregularly arranged one would feel cold, at others, warmth. The most important disagreement in the results found was between Goldscheider on the one side and Blix, with practically all later workers, on the other. Goldscheider discovered warm and cold points thickly scattered everywhere on the skin; for example, on the back of the hand there were 68 cold spots and 56 warm spots on a square centimetre. Blix reported that they were much farther apart, and all later investigators have confirmed his results. Sommer counted carefully the number in many square centimetres and found that there were from 6 to 24 cold spots, and from 0 to 3 warm spots, to the square centimetre. He gave as his average 12 to 13 cold and 1 to 2 warm spots. His estimate for the whole body was 500,000 cold and 30,000 warm spots.

Indirect Evidence of the Existence of Warm and Cold Spots. — Many of the earlier theories assumed that there must be a single organ for warmth and cold. Hering, for example, had a theory which would make warm and cold depend upon assimilation and dissimilation in the single organ, in very much the same way that his complementary colors depended upon those processes in the single color organ. It was therefore essential when the spots were first mapped to prove by other evidence that the spots were distinct. Certain characteristic differences in the way the two organs respond and in the substances that stimulate them pro-

vided this evidence. 1. It takes considerably longer to stimulate the warm spots than the cold spots, perhaps an evidence that the former are farther from the surface. 2. Certain inadequate stimuli will affect one but not the

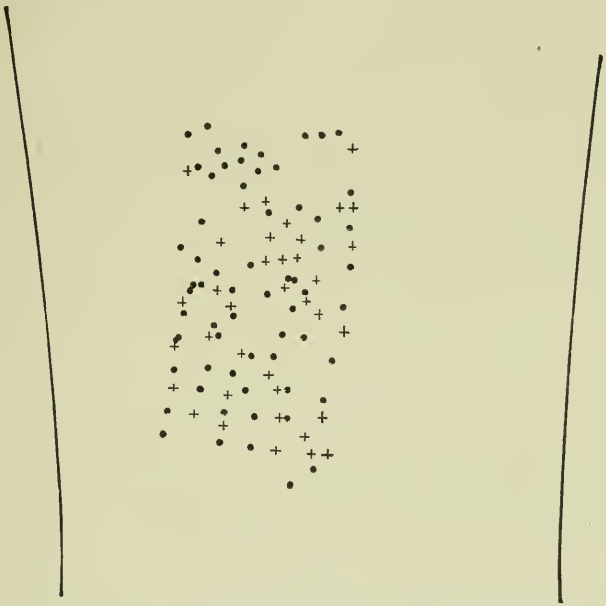

FIG. 56. — Map of temperature spots on volar surface of the forearm. The dots represent warm spots as tested at a temperature of 41–48° C.; the crosses, cold spots tested at 10°. (From Howell after von Frey.)

other. Cold is particularly easy to excite by induction currents, by pressure, or even by heat. Menthol stimulates the cold, carbon dioxide the warm organs. 3. There are certain larger areas of the body in which only one sort of sensation will be found. Thus on the cornea and conjunctiva of the eye cold alone is felt,

warmth is lacking altogether. That there are different organs for cold and for warmth is not now disputed.

The Temperature Scale. — The more detailed relation between the physical temperature and the sensations that result from the stimulation may be given. The

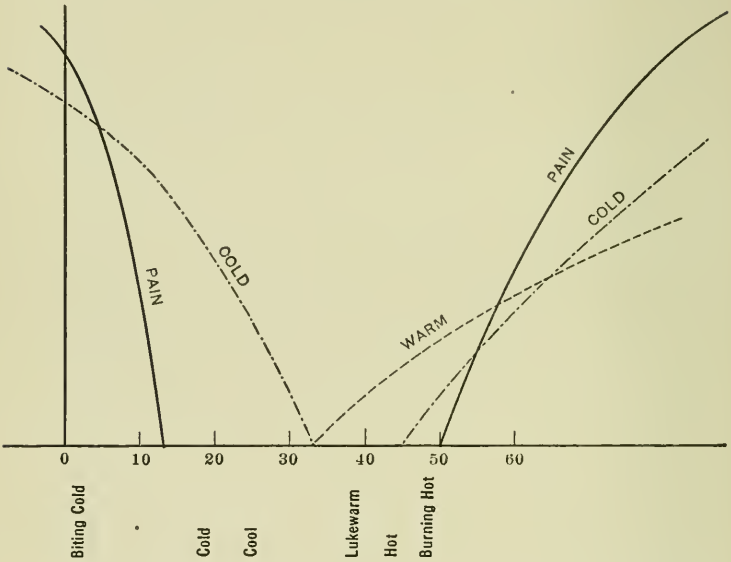

FIG. 57. — Temperature scale. Shows the sense organs stimulated and the degree of stimulation at different temperatures. Figures on the base line indicate the temperature in centigrade, the height the degree of stimulation. (After von Frey.)

critical point for most purposes is the so-called physiological zero point that separates cold from warm. This point varies much with the temperature to which the skin has been adapted. For a covered part of the body, it is apparently in the neighborhood of from 28° to 30° C.; on the back of the hand, it has been found to

vary between 23° and 33°, and after the hand has been immersed in water at 11° for some time water at 12° seems warm, and it may similarly be adapted for temperatures of 39°. The width of the indifference point seldom is greater than 0.5°. If we assume an indifference point at 30° C., below it the cold spots alone are stimulated to somewhere in the neighborhood of 10°, where pain is added to the complex. Above, one obtains warmth alone up to 45°. Here the cold spots are excited in addition to the warmth, and the combination gives hot as opposed to lukewarm. This excitation of the cold organ by a hot stimulus gives what is known as a paradoxical cold. The fact was first discovered by Alrutz and has been confirmed by von Frey. One experiment performed by Alrutz was to fatigue the warm spots in the foot by keeping it immersed for some time in warm water and then to swing it quickly through hot water. The hot water then seemed cold. Above 50° to 55° the sensation of burning heat makes its appearance as a consequence of the mixture of pain with the other sensations. The question naturally arose as to whether there was a paradoxical warmth at the lower ranges similar to the paradoxical cold. The burning sensation after long exposure to cold suggests that the warm spots might be stimulated. Experiments by Alrutz and Thunberg, however, gave no warrant for the assumption. The warm or hot sensations at low temperatures are probably due to the mixture of sensations of pain with some tingling due to changes in circulation. Figure 57 shows these various phenomena in diagrammatic form.

Mechanical Cutaneous Sensations. — Very much the same distinction may be made between pressure and pain as between warm and cold. Goldscheider also discovered that only certain points on the body would respond to pressure. There was approximately the same difference of opinion between Goldscheider and the others as to the number of spots. Goldscheider found many, the others relatively few. Von Frey, who has done the most careful and most recent work on the pressure sensation, found that there are from 0 to 300 per square centimetre. On the whole body surface, excluding the head where they are the most numerous, he estimates there are approximately 500,000. They are more numerous than either kind of temperature spots. In determining their position von Frey used fine hairs mounted on matches or similar small bits of wood. These gave a very small point and a constant pressure. Wherever there were hairs on the body he found that the pressure spots corresponded to them. They are also found on the surfaces free from hairs.

Sensations of Pain. — Pain has been even more in dispute than the other senses. Until von Frey's[1] work in 1896 it had usually been held, either that pain was a feeling, not a sensation at all, or, if it was a sensation, that it must be regarded as due merely to the over-stimulation of the pressure organ. Goldscheider in his investigations modified this view slightly. Pain was indeed carried to the spinal cord by the same neurones as pressure, but there took a different course. While the pressure sensation continued by the same neurone

[1] Leipziger Abhandlung, 1896.

up the posterior columns, the intense impressions were supposed to force a way across a synapse to new neurones with cells in the central gray and take another path. As evidence that there is this more difficult path through the central gray, Goldscheider adduces the long time required to receive pain sensations. The reaction time for pressure is from 0.12 to 0.2, while the time for pain rises to 0.6 to 0.8 second. He uses this theory also to explain summation pains such as those involved in the Chinese water torture, in which drops of water are permitted to fall for a long time upon the same point until the successive slight stimuli give rise to an unbearable pain. The summation is assumed to take place in the cells of the cord. Also the effects in the disease syringomyelia are mentioned as confirmatory of his theory. In this disease an infection extends from the central canal, destroying the cells in the surrounding gray matter. Patients suffering from this disease feel only pressure and cold in certain areas of the skin, but have no sensations of pain and warmth. Goldscheider interpreted this to mean that the paths for pain were destroyed, while the paths through the white matter were left intact. Goldscheider, too, explained on this theory the 'referred pains' so prominent in most diseases. He assumes that two or more regions of the body are connected with the same cells in the cord. Thus he would say that the mucous membrane of the stomach and the skin of the back were connected with the same cells in the cord. When certain disturbances of the stomach developed, the excitation of its nerves would be carried to the cells in the cord that gave rise

to the sensation of pain, and the sensation would be carried to the cortex. But since the same cells also transmit pain sensations from the middle of the back, and we are much more familiar with those, the pain would be referred to the known region, the back, rather than to the unknown region, a region that had never been seen and where voluntary contact had never produced pains. A somewhat similar theory of referred pains has been given by Head[1] without accepting the other portions of Goldscheider's theory.

Pain Spots. — More recent investigations have shown that the first part of Goldscheider's theory, that pain and pressure are carried to the cord by the same nerves, is probably incorrect. Von Frey, in particular, by very careful mapping of the skin has shown that there are special pain spots in the skin in addition to the pressure and temperature spots. The mapping was on an enlarged scale diagram of the small portion of the skin worked with. The skin was explored with a sharpened horse hair under a magnifying glass, and it was found that sensations of pain were given only at certain points, mostly in the small lines of depression on the skin. These were found to be much less sensitive than the pressure spots, required about one thousand times as great a pressure to stimulate them, and were much more numerous than any other, on the average, one hundred to the square centimetre. It was estimated that there are between two and four million pain spots on the surface of the body. Much corroboratory evidence has been brought to confirm the results of mapping the

[1] Brain, 1893.

FIG. 58. — Termination of sensory nerve-fibres in the mucosa and epithelium of the cat. (From Huber.)

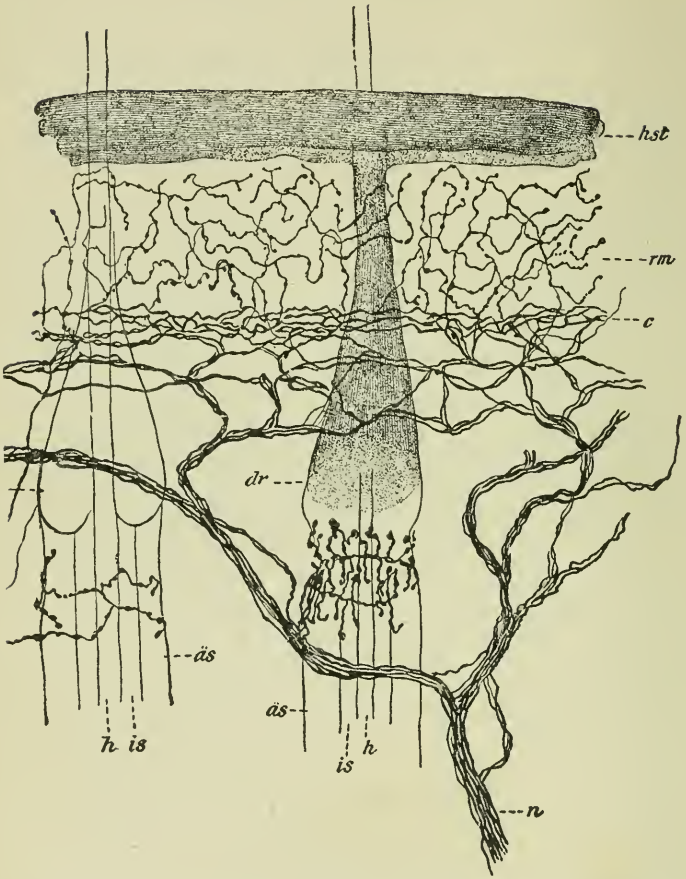

FIG. 59. — Nerve endings in skin and about hair follicles. *c*, superficial plexus of fibres in skin (free nerve endings are still nearer the surface); *h*, the hair with nerves about root. (From Barker, after Retzius.)

spots. It has been found that there are some parts of the body, the conjunctiva of the eye, *e.g.*, where there are pain spots but no pressure spots; others, as the inner

lining of the cheek, where there are pressure spots but no pain spots. Another bit of evidence depends upon the slow response to pain mentioned above. If a pressure spot be stimulated by a slight alternating electric current with alternations of fifty or sixty per second, the separate alternations will be noticed. If, on the contrary, the current be applied to a pain spot, there is a continuous sharp sensation.

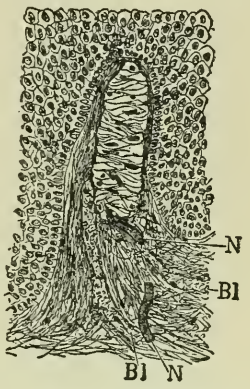

Fig. 60. — Tactile corpuscle of Meissner from the skin of the toe. *N*, nerve fibre. (From Barker.)

Cutaneous Sense Organs. — The sense organs for these different sensations have been determined with varying degrees of certainty. Pressure spots seem closely connected with the hairs on the parts of the body where there are hairs. The spot that responds is always just over the root of a hair (Fig. 59). It is probable that the nerve about the root is stimulated by the hair which acts as a lever as it is bent. On the surfaces without hairs, palms and soles of the feet, von Frey suggests that the Meissner corpuscle (Fig. 60) is the organ. Pain spots are ascribed to the free nerve endings (Fig. 58). These come closest to the surface of any of the end organs in the skin and the sensations of pain are aroused by the most superficial stimulations. Acids that affect only the epidermis give pain sensations without sensations of pressure or temperature. It is more difficult to determine the organs for tempera-

ture and the results are less trustworthy. Following von Frey again, we may regard the end organs of Krause (Fig. 61) as the sense organs of cold, since they with the free nerve endings are the only sense organs found in the conjunctiva, where also only pain and cold can be felt. Because the sensations of warmth seem to originate well below the surface and the organ of Ruffini also is found relatively deep, that has been regarded as the sense organ of warmth (Fig. 62).

Regeneration of Cutaneous Sensations. — An experiment performed by Head and Rivers tends to establish a second classification of cutaneous sensations that has not been brought into complete agreement with the one given above. They cut the ulnar nerve where it is near the surface at the elbow and then studied the sensations that remained and the gradual reappearance of sensations as the nerve regenerated. At once, after the nerve was cut, all sensations from the skin proper disappeared. Neither pressure nor pain, warmth nor cold, could be felt. When more intense stimulation was applied, pressure and pain could be felt from the tissues under the skin, of approximately the same quality as from the normal deeper tissue in the arm. This they call the deeper lying sensibility. After the lapse of forty-three days, sensations first began to return to

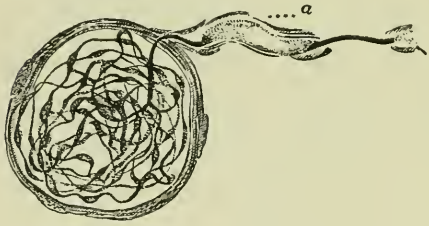

Fig. 61. — End bulb of Krause. (From Barker.)

the skin. The first evidence of regaining sensation was in the diminution of the area insensitive to pain. On the one hundred twelfth day sensations of cold made their appearance, and the area sensitive to pain had much increased. Nearly two months later the hairs were found to be sensitive to light touch and a few warm spots made their appearance. One hundred and ninety days after the operation all of the sense qualities had returned over approximately the entire area. But each of the sensations was limited in some way as compared with the normal. Temperatures below 37° C. and above 27° C. could not be felt at all. Pain sensations could be felt only from unusually intense excitations, and then were exceedingly disagreeable and diffuse, and were generally referred to some point at a distance from the one stimulated. Touch could be felt only on the hairs, — when an area was shaved, no touch was felt. The sen-

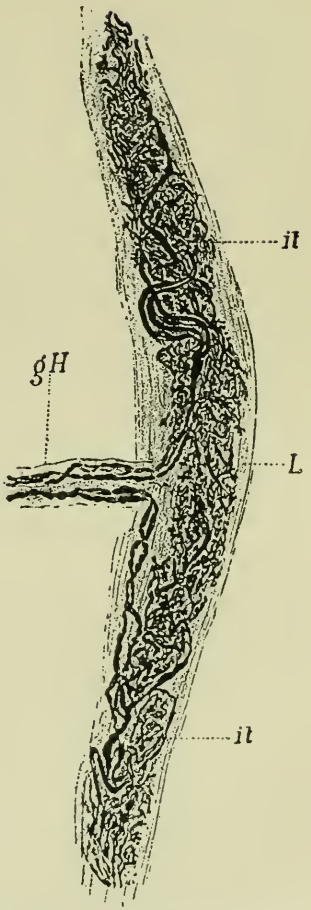

FIG. 62. — End organ of Ruffini. (From Barker.)

sibility producing this condition the investigators call *protopathic*.

Curiously enough there was discovered one small triangle in the affected region in which all the qualities were present that were lacking from the rest. Temperatures between 27° and 37° C. could be noticed but none of the extremes. No pain was felt; pricks gave mere sensations of contact and were always correctly localized. Perhaps most remarkable of all, light contact with cotton wool was appreciated on this small triangle from the beginning and was correctly localized whether hairs were or were not stimulated. This more highly developed and more accurate sensibility was known as the *epicritic*. After the lapse of a year, the epicritic sense returned to the entire area. The protopathic sensibility had reappeared in the small triangle with epicritic sensitivity only, one hundred ninety-eight days after the operation. This experiment indicates that three sets of sensory nerves supply any member. One is found in the deep tissues, the two others in the skin. Of the latter one provides the coarser, more intense sensations, the other the more delicate. The protopathic is stimulated only by relatively intense pressure and that only on the hairs; very intense stimuli also give pain. It also is affected by the extremes of temperature alone. The epicritic sense, on the other hand, supplies the gaps left by this sense; it appreciates moderate temperatures and slight pressures. The relation between the separate spots that have been shown to produce the specific sensations and the epicritic and protopathic sensibilities has not been completely

worked out. It seems difficult at first sight to harmonize the two sets of results, and another series of observations on a subject with a regenerating nerve which shall include mapping of the spots at different stages is desirable to complete our knowledge, and to determine how far the two can be made to agree.[1]

Sensations of Taste

Gustatory Sensations. — While tactual sensations have been found much more numerous than was thought as knowledge about them increases, sensations of taste have been diminished in number quite as definitely and markedly. The popular mind to-day and the scientific opinion of one hundred years ago assumes that there are a very large number of taste qualities. Even after experiments had been made, it was generally believed that at least six could be distinguished. The older list included nauseating tastes, aromatic, and other qualities that we now know to be derived from smell. Chevreul showed in 1824 that these must be smell qualities by his discovery that they disappeared upon closing the nostrils. Until relatively recently salt, sweet, sour, bitter, metallic, and alkaline were regarded as the primary tastes. The metallic seems on closer experimentation to be a compound of taste with smell and with mechanical and perhaps muscular sensations. The metallic surface may produce slight muscular contractions in the neighborhood of contact which add to the other taste and smell sensations to produce a complex. Alka-

[1] Rivers and Head, A Human Experiment in Nerve Division, Brain, xxxi, 323.

lies if strong may make the tongue slippery and may also produce puckering of the surface of the tongue. Von Frey has shown by closing the nostrils while tasting that alkalies also contain odors. When the tongue is at rest and the nose closed, the only sensation is a slight bitter. Eliminating all sensations of smell, which fur-

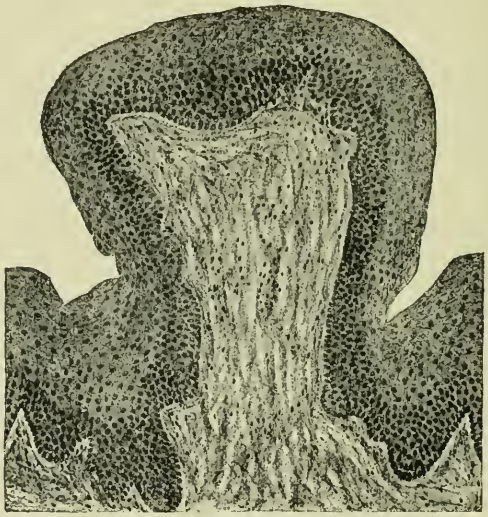

Fig. 63. — Fungiform papilla from human tongue. (From Huber.)

nish a large part of what is called taste in gastronomic relations, and all tactual and temperature sensations, such as the biting of spices, etc., we have left only four true tastes, — sweet, salt, sour, and bitter.

Sense Organs of Taste. — The problem of the organ of taste, and its specific type of reaction, is similar to the same problem on the skin, but slightly more complicated. The sense endings of taste are found primarily

upon the tongue, but also in some numbers upon the soft palate, upon the cords of the larynx, the epiglottis, and in children also on the inner lining of the cheek. On the tongue the end-organs are the papillæ. These are elevations set deep in the mucosa. The sense ends

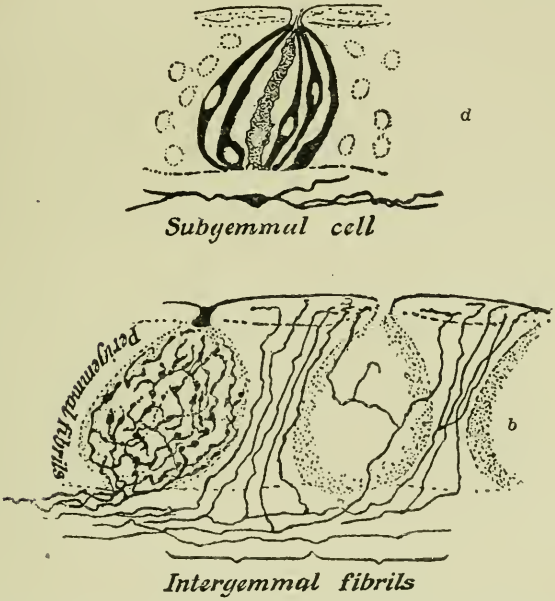

FIG. 64. — Taste buds and endings of gustatory nerve; *a* shows taste cells about a central supporting cell; *b*, fibrils around and between the taste-buds. (From Barker.)

are on the sides of the resulting folds. The most striking are the circumvallate papillæ, from seven to twelve circular depressions, much like the moat of a walled town, arranged in an angle upon the back of the tongue. The most numerous type in man are the fungi-

form, whose small red openings may be seen upon the tip of the tongue. In some humans the foliate papillæ are present and have sense organs. They are very prominent in animals. The real sense ending is the taste bud or beaker. These are collections of taste cells and supporting cells arranged in the form of a bud. The taste cells have hairs on their ends that extend into the papillæ where they come into contact with the saliva in which the chemical substance that gives rise to the taste has been dissolved. Around the taste cells are nerve fibrils bare of their medullary sheaths. The function of the papillæ is apparently to catch the saliva and permit it to come into contact with the taste cells, and there to start the nervous impulse.

Doctrine of Specific Energies for Taste. — Much discussion has been devoted to the question whether a single taste bud in the papillæ can give rise to one only or to more than one sensation. Experiments performed by Oehrwall of stimulating the papillæ separately showed that more than one sensation might be received through a single papilla. He mapped accurately 125 papillæ and then stimulated each separately with solutions of sugar, quinine, and tartaric acid. Of these, 27 gave no response at all, 60 responded to all three substances, 12 gave acid only, 3 sweet only, none bitter only, 4 gave sweet and bitter, 12 sweet and acid, 7 acid and bitter. From this experiment, which has been repeated by several investigators with approximately the same result, it is evident that the papillæ cannot be regarded as the organs of different special sense qualities as are the spots on the skin. It is suggested

by the supporters of the doctrine of specific energies that the immediate sense end is the taste bud and that, as there are always many of these in each papilla, it is possible that each taste corresponds to a particular sort of nerve end, but that several different kinds are found in each papilla. As the separate beakers cannot be stimulated individually, this assumption cannot be confirmed directly. Some indirect evidence in its favor is offered by the fact that on the application of certain drugs the tastes disappear one at a time, presumably due to the fact that the primary end organs are affected with different ease. Thus, cocaine applied to the tongue destroys first the sensation of bitter, and the others in succession, while gymnemic acid first destroys the sensation sweet. Similarly, the distribution of the taste sensitivity on the tongue tends to confirm the same theory. Bitter is most prominent on the back of the tongue, — in some individuals is confined to that region; sweet is more pronounced on the tip, sour on the sides, while salt is more generally distributed. The distribution varies from individual to individual. In some, bitter will be lacking altogether on the tip, while in others it is present, but in few papillæ. A similar statement may be made for each of the taste qualities. As further evidence that there are specific endings for each quality, the same substance will produce a different taste as it is applied to one part of the tongue or the other: sodium sulphate has a sweet taste on the tip, a bitter taste on the back of the tongue, a difference that must be due to the organ stimulated. Similarly, pressure or electrical stimulation of the chorda

tympani, one of the nerves of taste, where it passes through the middle ear may produce sensations of taste. Still another bit of evidence for the independence of the organs for the different tastes is difference in the time required for stimulation. On the tip of the tongue salt requires from 0.25–0.72 second to be appreciated, sweet, 0.30–0.85, sour, 0.64–.070, bitter, .1–2 seconds. The longer time for bitter is especially striking. While the doctrine of specific energies is not open to direct test, the indirect evidence, so far as it exists, supports the hypothesis.

Attempts have been made to discover some relation between the chemical composition of substances and their tastes. As is well known, acids are sour so generally that the two words are popularly synonymous as applied to taste, and in German are designated by the same word. There are, however, many exceptions on both sides. For the other qualities the lack of relation between the chemical composition and taste is striking. The more familiar sweets are carbohydrates, but lead acetate, salts of the other heavy metals, and even some alkalies have sweet as one of the component tastes. Much the same statement may be made of the bitter substances. Usually they have a complex molecule, and the more complex, the more bitter, but no more accurate law has been developed. The simple salts are usually more or less salt, but there are many exceptions. In general, the attempts to correlate taste and chemical composition have led to no noteworthy results.

Taste Fusions and Taste Contrasts. — The taste qualities show some of the interrelations found in vision.

Tastes mix with each other, with the cutaneous sensitivities, and with odors to produce complexes that are not readily analyzable. The statements hold less for taste alone than for mixtures with the cutaneous and olfactory senses. It seems that sweet and sour, sweet and bitter, combine in foods to advantage. Salt and sweet have approximately the relation of complementary colors. When mixed in weak solutions, Kiesow found that they nullify each other. Also when applied to neighboring areas of the tongue, they reënforce each other, *i.e.* show contrast effects. Thus if one pour upon one side of the tongue a solution of sugar too weak to be tasted, and upon the other a salt solution, the sugar will be tasted. Even distilled water will by the same means be given a sweet taste. Other tastes, as sweet and bitter, applied to opposite sides of the tongue, when intense, may alternate, first one appears, then the other, a process resembling binocular rivalry of colors.

The nerves of taste offer some complication. According to Zander, there are three nerves of taste and one of cutaneous sensibility. Of the true taste nerves, the glosso-pharyngeal, the ninth, supplies the back portion of the tongue; the vagus supplies the taste buds of the larynx and epiglottis and a small area on the very back of the tongue; while the chorda tympani carries the sensations from the forward areas. The chorda tympani enters the tongue as a part of the lingualis, the other portion of which is a branch of the trigeminus, and is the nerve of cutaneous sensibility. In its midcourse it is alone, and then enters the brain stem as part of the intermediate nerve.

Olfactory Sensations. — The organ for smell is situated in a narrow cleft at the very top of the nasal cavity, just under the olfactory lobe at the base of the brain. The olfactory area is marked by a brown pigment which extends over the upper portion of the sep-

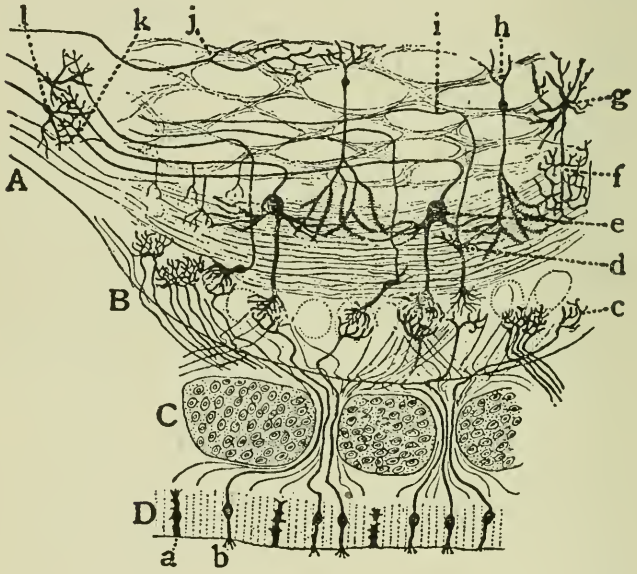

FIG. 65. — Olfactory apparatus. *D*, the olfactory membrane and endings; *B*, glomeruli where end-brush of olfactory neurones connects with dendrite of the more central neurones. (From Barker after Ramon y Cajal.)

tum and the roof of the olfactory fissure. The olfactory area is much smaller in man than in animals that make more use of the olfactory sense, and much smaller in man than was earlier supposed, since the brown pigment, which was at first assumed to mark it, is more widely distributed than the olfactory sense endings. The

olfactory fissure is above the direct respiratory path — only eddies of the air inspired or expired reach it. This is a protective measure, as dust and other harmful impurities are largely prevented from affecting the endings. The end organ proper is found in the olfactory cells, true nerve cells, which here alone reach the outer surface of the body. These cells end in hairs that project slightly from the surface. The axones of the cells pass upwards through numerous openings in the skull to make connections in the glomeruli with neurones of the olfactory lobe, and thence to connect with the cortical areas for smell. Between the olfactory cells are supporting cells. The chemical substance that gives rise to the odor is carried in the inspired or expired air and comes into direct contact with the hairs of the olfactory cells, where we may assume that the chemical reaction excites the nervous impulse.

Olfactory Qualities. — How many sensations of smell there are is still a moot question. The organ is so situated that no direct experiment may be made upon it, and the indirect experiments either have not been carried far enough or are inaccurate. Aronsohn long ago attempted to determine the number by a fatigue method. His theory assumed that one might tire the organ by smelling some one substance, rosewater, *e.g.*, until that substance could no longer be detected, and then while the fatigue persisted, test the odors of different substances. Any that could still be detected would belong to some other class, must be sensed through some other organ; those that could not be distinguished would belong to the same class. The method has been proved

to be practical, but the large number of substances to be tested and the difficulty in knowing whether the organ is still fatigued for the standard odor have prevented its extensive application. Other evidence of the existence of separate olfactory organs is furnished by pathology. In certain diseases of the olfactory region, the odor of certain substances will be lost while others will be retained. But the observations have not been carried far enough to give an accurate classification.

Zwaardemaaker, who has done most work on the subject, has suggested the following nine groups of odors:

1. Æthereal. Certain fruit odors, ether, the esters, etc.
2. Aromatic. Spices, resin, camphor, etc.
3. Fragrant. Odors of certain flowers and perfumes, balsam.
4. Ambrosiac. Amber and musk.
5. Alliaceous. Onions, garlic, rubber, chlorine, sulphur, etc.
6. Empyreumatic. Smoke, benzol, phenol, etc.
7. Hircine. Goat odors, caproic acid, perspiration, etc.
8. Repulsive odors. Opium, acanthus, etc.
9. Nauseating. Decaying flesh, substances that excite incipient vomiting reflexes.

While this classification is the best that we have, many obvious objections may be made to it. Nagel has found that in several instances substances belonging to the same class will be shown by the fatigue test to be excited in different organs. Evidently, too, several of the groups are characterized by qualities

altogether foreign to odors. Thus the offensive odors owe their name and common quality to the unpleasant feeling they arouse; the empyreumatic to the pain quality, a cutaneous sensation derived through the fifth nerve, not through the sense of smell; and the nauseating to slight movements in the œsophagus. While each of these processes, together with taste, mixes with odors to produce a percept that is not immediately analyzable, they do not constitute true odors. All that can be said, then, is that there is a large number of odors, how many we do not know, each of which probably has its own sense organ. These qualities mix with the cutaneous sensations from the mucous membranes of the nose, — one quality of smoke, *e.g.*, is the same from the eyes as from the nose, — and with tastes. We usually do not distinguish the different components: if the complex comes from food in the mouth, we call the whole a taste; if from the air outside, we call the whole an odor.

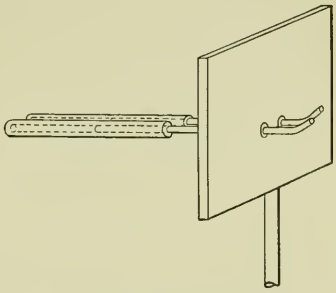

FIG. 66. — Zwaardemaaker's olfactometer. (From Titchener.)

Attempts have been made to connect the qualities of smell with the chemical composition of substances. In general it may be said that most odorous substances are found in the fifth, sixth, and seventh groups in the system of Mendelejeff. Haycraft has also shown that in many cases the intensity of the smell in a group

increases fairly regularly with the complexity of the molecule. There are exceptions to these rules and no complete formulation may be made of them. It is probable that the chemical substance is borne on the inhaled and in less degree by the exhaled air to the olfactory nerves and there by direct chemical action arouses the nervous excitation.

Mixtures and Compensations of Odors. — Mixtures and compensations of smells can be easily demonstrated. For these, as for making all quantitative tests of odors, Zwaardemaaker made use of an instrument he called the olfactometer. In essentials it consists of one tube with a curved end to be inserted in the nostrils, and of a second tube of larger size containing an inner lining of the substance to be investigated to be slipped over the former. The amount of stimulation is measured by the area of the outer tube exposed beyond the inner. If they are even, the air entering the inner tube absorbs none of the substance on the outer; and the more the outer projects beyond the inner, the more saturated with particles is the air that enters the nostril. In the double olfactometer of this sort a tube is applied to each nostril. It is found that if certain substances, tolu balsam and iodoform, *e.g.*, are applied either to the same or different nostrils at the same time, they cancel each other and no odor is sensed. Other substances produce mixed odors that may or may not be analyzed into their components. Xylol and turpentine fuse to form a new odor and many others can be mentioned. Certain of these mixed odors are given off by simple substances, as can be shown by the fatigue test. Thus

if propionic acid be smelled for some time, the original odor will lose one of its components and assume a different quality.

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Organic Sensations

Kinæsthetic Sensations. — To these traditional five senses of man, modern science has added a number of others. One of the most important is the kinæsthetic, the sense by which we appreciate the movements of our own members. The muscle sense played a considerable part in the English psychology of the last century, — Thomas Brown and the Mills made use of it, — but the first experimental work of importance on the subject was carried on by Goldscheider in the late eighties of the last century. Goldscheider adduced evidence that the more delicate sensitivity to movement was in the joints rather than in the muscles, as had been earlier supposed. His main bit of evidence for this was that the sensation of movement is markedly diminished if an induction current is passed through the joint as the member is bent. Evidently there are three possible sources of sensation for movement, the external skin, which must be wrinkled at the joint as it bends, the muscles and tendons which are known to be well supplied with sensory endings, and the joint. Goldscheider assumed on the basis of his experiments that the joint

surfaces were the organs in spite of the fact that there are known to be no sensory nerves ending on the joint surface, and that an experiment that he made himself indicated that the membrane on the joint, the synovial membrane, had a very slight sensitivity.

By anæsthetizing these possible sources of sensation one after another, it is possible to determine their order of importance in making known the movements. Experiments are made by placing the member to be tested, usually the forearm, on a hinged board, with the joint over the hinge, and then raising the board until the movement is first noticed. The least movement of the arm that can be appreciated is about half a degree. If the external skin be anæsthetized, this will not be changed. The skin, then, must be less important than the internal sense organs. Goldscheider found that if an induction current be passed through the joint, there must be a considerable increase in the movement before a sensation is produced. He regarded this as evidence that the joints were essentially the organs of movement. The writer repeated the experiments and found that although when the elbow or knee joint was anæsthetized by passing an induction current through it the sensitivity for movement was reduced, it was also reduced quite as much when an induction current was passed through the wrist or ankle joint, or the muscles near them, and still more reduced when passed through both at the same time.[1] From this it seems that the essential organs in the appreciation of movement

[1] Pillsbury, Does the Sensation of Movement Originate in the Joint? Amer. Journ. of Psychology, 1901. 346–353.

are the muscles and tendons with the sensory nerve ends that are embedded in them. These results have recently been confirmed by von Frey.[1] This hypothesis is strengthened by the histological evidence that the joint surfaces are bare of sense organs, and by the fact that careful observation indicates that the movement of the elbow is ordinarily felt either in the wrist or fingers. Instead, then, of regarding the kinæsthetic impressions as coming primarily from rubbing of joint surfaces, we may regard the excitation of the sensory endings in the muscles and tendons by the contraction of the muscle or the stretching of the tendon as the source of our sensations of movement. To this may be added as a subsidiary factor the wrinkling of the joint capsule, which also contains sensory endings.

These kinæsthetic impressions play a very large part in our mental life. It is of course important to know where the different members of the body are at any moment. In addition to this the kinæsthetic sensations contribute very largely to the coloring of other experiences; they guide the different movements and constitute an important element in the emotions. We shall have occasion to make use of them often in the later chapters.

The Static Sense. — Closely related to the kinæsthetic sense in function is the sense of equilibrium. This is also a sense of relatively recent discovery. In 1872 Crum Brown, Breuer, and Mach independently reached the conclusion that the portion of the inner ear not used in hearing, the so-called vestibular portion of the

[1] Von Frey, Studien über den Kraftsinn. Zeitschr. f. Biologie, 1913. 129–154.

ear, is closely connected with keeping the balance, and with the appreciation of the movements of the body as a whole. The evidence accumulated since is altogether convincing. The organs involved are the sacculus, the utriculus, and the semicircular canals, named in order from the vestibule. The sacculus is a membranous sack floating in the lymph contained in an enlargement of the bony labyrinth. This opening communicates with the vestibule, and the lymph is continuous with the lymph of the cochlea. A branch of the vestibular nerve enters the sacculus, and ends in hair cells. Among the hairs are small crystals of calcium carbonate, the otoliths. The utriculus is a similar, somewhat larger sack in another cavity connected with the sacculus by a small opening. The nerve endings are similar to those of the sacculus. From the utriculus extend the semicircular canals, one in each plane of space. They have two openings into the utriculus, making possible a movement of the lymph through the complete semicircle. Near one opening of each canal into the utriculus are small swellings, the ampullæ. In these end the branches of the vestibular nerve that go to each canal. The nerves end in long hairs that protrude into the lymph of the ampullæ. The different branches of the vestibular nerve unite with each other and join the cochlear branch to constitute the eighth nerve. In the brain stem the two branches have separate nuclei. The nucleus of the vestibular branch has connections primarily with the cerebellum and with the nuclei of the motor nerves of the eye.

The evidence that the function of these organs is

primarily to keep the balance is now manifold. The earlier investigators proved that sectioning a semicircular canal in a pigeon disturbed its balance and the tonus of its muscles, and at first made it stand with the head drawn to one side. It was also shown that passing a strong electric current through the ears would produce a turning of the head. Studies of patients with diseased vestibular organs showed characteristic loss of some one function according to the part affected and the length of time the disease had lasted. Many of the deaf are also defective in keeping the equilibrium. If one registers the movements they make when standing erect with eyes closed, it is found that they sway much more than the normal individual. It is also found that about half the deaf do not have the compensating eye movements, *i.e.* the movements of the eyes that make the eyes turn in the direction opposed to that taken by the head, that permit the eyes to fixate a point reflexly in spite of movements of head or body. In many cases the vestibular portion of the ear is normal when the cochlea is affected.

Streeter has shown that if he destroys the vestibular region in the tadpole, the frog that develops from it has no sense of position, is as likely to swim on its back or side as right side up. Kreidl inserted iron filings in the otocysts of the crayfish when they were opened by the shedding of the shell, in place of the particles of sand that normally find their way into the cavities at that time. After the new shell was grown he found that if he brought a magnet over the crayfish they would at once turn and swim on their backs. Evidently the

attraction of gravitation for the sand particles had been replaced by the magnetic attraction for the iron filings. These various lines of experimental evidence, together with the probability raised by the close central connection of the nerve with the cerebellum and with oculomotor centres, are conclusive proof that the vestibule contains the organ for the static sense, and is the source of reflexes for many eye movements and for keeping the balance, as well as for keeping the general tonus of the muscles.

The Organs of Equilibration and their Stimuli. — The mechanism of the stimulation of the sense organs may be made out in a measure from the experimental data and the structure of the organs. Movements of the body as a whole probably stimulate the sacculus and utriculus primarily. As the body moves forward, the otoliths are left behind for a moment through their own inertia and so move the hairs and stimulate the nerves. This excitation occurs only at the start; soon the otoliths take on the motion of the body and no further excitation occurs. The opposite stimulation is given as the motion ceases; the otoliths continue to move forward under their own inertia for a time and produce the same effect as if the person were starting backward. This may be noticed as a train comes to a stop. For an instant one seems to be starting backwards. Going up or down, as in an elevator, also displaces the otoliths and gives the corresponding sensations. Movements of rotation and of turning the head in the different planes affect the semicircular canals. The hairs in the ampullæ are probably stimulated by the movements of

the liquid and these stimulate the corresponding nerves.

It is a question whether these excitations give rise to a sensation of their own or whether they merely excite reflexes and these reflexes are appreciated. Violent excitations produce sensations of giddiness and finally nausea and vomiting, as in seasickness. Slighter excitations only call out movements of the eyes and the movements required to keep the balance. The same sensations of giddiness and even nausea may be produced by rapid irregular movements of the eyes without movements of the body. All of this speaks for the view that the sensation of giddiness is not a true sensation of the vestibular nerve, but rather a sensation from the alimentary canal, due to reflexes excited by the organs of equilibrium. On this theory the vestibular nerve excites no peculiar sensation, but serves to adjust the different muscles of the body, including primarily the eye muscles, to the various movements of the body. The sensations arise from the reflexes when they become intense. It should be noted that visual sensations, kinæsthetic sensations, and sensations due to displacement of the large visceral organs also aid in keeping the balance and in appreciating the movements of the body. The deaf who have lost the sensitivity of the vestibule can, by means of these other organs, still retain the balance, though less accurately.

Hunger and Thirst, General Sensibility. — Of the sensations from the inner organs, hunger and thirst probably bulk largest in the daily life of man. Hunger has been recently investigated by Carlson and by Can-

non.[1] They find in man and dogs that it is a comparatively transient accompaniment of the deprivation of food. During a period from three to five days after food is stopped, the sensations become continually weaker and gradually practically disappear. They are, however, rearoused by sight of food or by anything that suggests food. The sensations were found to be due to contractions of the walls of the stomach. Records of these contractions were taken by swallowing a rubber sack or balloon with tube attached which could be inflated to fill the stomach, and then registering, upon a revolving drum, the compressions of the air in the balloon. These contractions are particularly vigorous when hunger is keenest, and in general run parallel to the sensations. Thirst has its seat in the back of the throat. It is apparently due to the drying of the membrane there. It may be relieved by laving the back of the mouth with citric acid or by taking liquid into the system, either through the mouth, through an artificial opening into the stomach, or directly into the circulation. Each of these processes leads to the moistening of the membrane in question. In addition to the qualities of sensation discussed, there are a vast number of other sensations which fuse in the general complex of organic sensibility. It is useless to speculate upon their quality or their number. With the advance of science others will undoubtedly be separated from the mass and be recognized as separate senses; some already have names ascribed to them in popular speech.

[1] Cannon, The Physiological Processes in Pain, Hunger, Fear, and Rage.

Of these, the more external of tickling, pins and needles, itching, have been explained in different ways; pins and needles by changes in circulation; tickling by contractions, in the skin muscles, survivals of the fully developed skin muscles in animals, or, by certain authors, as due to stimulation of tickle spots, a fifth form of sensory spot in the skin. No one of the explanations can be regarded as more than hypothetical. The internal sensations are even less known and few if any distinctive names can be given. Such names as are given refer to particular complexes, such as those present in the different emotions, rather than to specific sensations. Some of these inner sensations are of the same quality as the cutaneous sensations, and are always fused with sensations from the contraction of various muscles. They are most frequently fused into the vague feelings of well-being or ill-being, and are attended to only as signs of health or of general bodily state.

The Doctrine of Specific Energies. — A final problem is the bearing of the results so far discussed upon the doctrine of specific energies. We have found that law convenient as an introduction to the study of sensation, and have used it as a guide throughout. But it is now time to determine how accurately our hypothesis harmonizes with the facts. The doctrine for convenience may be divided into different parts. 1. A nerve end when stimulated at all always gives rise to its own peculiar sensation. 2. There are as many nerve ends as there are specifically different sensations. 3. The quality of the sensation depends upon the character of the end organ rather than upon the nature of the

stimulus. If we examine these phases of the doctrine one by one, we find that the first holds so far as it is possible to test it at all accurately. It applies to the retina, to the end organs on the skin and on the tongue, less certainly to the olfactory organ. In discussing the problem we distinguish adequate and inadequate stimuli. An adequate stimulus is one that excites the organ in greatest perfection. Light is an adequate stimulus for the eye, sound waves for the ear, etc. Adequate stimuli give the full number of sense qualities of which the organ is capable. Other stimuli are inadequate. The electric current is an inadequate stimulus for all senses, pressure an inadequate stimulus for the eye, etc. Each of the sense organs mentioned may be excited by one or more inadequate stimuli, and when excited responds with a sensation of the quality peculiar to that sense. The number of stimuli that will excite the organ and the intensity of stimulation required vary from organ to organ and for the different sense qualities within the same organ. The sensation that arises when the organ is stimulated also shows various degrees of approximation to those excited by the adequate stimulus. On the skin, most of the organs may be excited by several stimuli and give approximately the same quality as that produced by the adequate stimulation. The olfactory endings are excited with difficulty and then, so far as is known, only by electrical stimuli, and the resulting quality is very uncertain. The location of the organ may account in part for the uncertainty of the result. The retina has an intermediate position in both respects. Mechanical and electrical stimuli at

least will affect it, and they produce several sensory responses, but not the variety or delicacy of effect produced by the light waves. While the law will not hold with the completeness that a firm believer might wish, still it can be said in general that sense organs may be affected by various stimuli, and when they respond, *if they respond at all*, the quality is that ordinarily given by that organ rather than the quality produced by the stimulus in the organ for which it is the adequate stimulus.

The second law is less definitely demonstrable. Except on the skin, one cannot prove that each sense quality has a separate nerve end. From what we know of the eye, the cones probably have more than one sense quality, and while one might assume that there are different chemical substances in each cone, it is hardly likely that there are different nerve ends. A case might be made out for separate taste buds for each quality; there is slight evidence for separate organs for each odor. In hearing, the Helmholtz theory depends for its truth upon the law rather than substantiates it. Strictly, then, the statement that there are as many qualities as there are sense organs and no more holds only for certain senses, and is to be regarded rather as a convenient guide to the discussion of sensation than as a fully substantiated fact. The third principle, that the quality of sensation depends upon the sense organ excited rather than upon the stimulus, holds approximately. Adequate stimuli excite the organ at a slighter intensity and give a richer quality in most of the sense organs. Nevertheless if one were to decide between the receiving organ

or the external stimulus as the determinant of the sensory quality, the receiving organ must be given the more important part.

There is also a question whether, granted that the sensations depend upon the specific characteristics of the nervous system, the determinants of the quality are to be found in the sense organ or more centrally in the nerves or their central connections. The evidence is conflicting from sense to sense. According to Nagel[1] there is no good evidence that colors can be excited except from the retina. Cutting the optic nerve or turning the eyes sharply to one side or the other gives rise to sensations of light, but he thinks both probably due to the accompanying pull upon the retina. Sensations of taste are with difficulty or not at all excited by inadequate stimuli upon the tongue, while mechanical stimuli upon the chorda tympani where it passes through the middle ear arouse them certainly and at comparatively slight intensities. In the skin it is apparently the end organ that gives the peculiar quality. Pressure upon the ulnar nerve gives sensations but not of the distinct qualities that may be aroused from the skin. One cannot decide definitely between sense organ and the more central regions. Of the central nervous organs, it seems that the nerves themselves are relatively indifferent. They conduct in either direction, and sensory nerves may be made to carry motor impulses by giving them connections with motor structures. Whether the cortical centres have a specific function is still an open question. It has been assumed

[1] Nagel, Handbuch der Physiologie, vol. iii, pp. 1–15.

by many authorities that the qualities of sensation depend upon the parts of the cortex excited. No actual evidence for it has been collected and it seems improbable that it could be obtained. In general, it may be said that the doctrine of specific energies of sensory ends lacks much of complete demonstration, but that what data we have tend to support rather than to refute it. On disputed points evidence is wanting rather than opposed.

Studies in Sensation Intensities. — Weber's Law

Sensation intensities offer an entirely different problem from qualities. Qualities, as we have seen, are ordinarily named, may be referred in some cases to sense organs, offer points of discrimination that may be recalled in memory, — in general stand out for themselves. Intensities, on the contrary, have none of these characteristics. We think of a sound as very faint, moderately or very loud, but that is all. Intensities have no real designations, and cannot be remembered at all accurately. It is perhaps not one-tenth as bright in this room to-day as it was when last the sun shone, but you do not appreciate the difference accurately. You think of this as a moderately dark day, but have little idea how much darker than yesterday. The same holds of weights. Most persons have great difficulty in deciding whether a package of an unknown substance weighs one pound or two, and would be altogether at a loss to decide whether more energy was exerted on the ear by a telephone held close to it or by a steam whistle at a distance.

Measurements of Sensation. — It has long been a problem among psychologists as to how intensities may be treated. The modern discussion of the matter may be said to date back to Fechner, who thought it would be possible to obtain a unit for the measurement of sensation intensities analogous to those employed in physical measurements. His assumption was that the barely distinguishable sensation difference, the difference limen as he called it, might be made a unit and any given sensation might be measured in terms of the number of such units it contained. This assumed that the only judgments that may be passed on intensities are that the sensation is or is not present, or that it is greater or less than another. The amount of sensation intensity that may be just noticed, the limen, was chosen by Fechner as the zero point in his scale. If one should start with the faintest sensation that comes to consciousness, and determine the addition that can just be noticed, the liminal sensation might be called sensation number one; the just noticeably different sensation, sensation number two; and if one should continue the process, it would be possible to determine the entire number of differences that could be noted in the series of sensations, and thus the entire number of sensation intensities in any sense department. It would also be possible to measure any sensation by the number of these unit intensities that were contained in it. Unfortunately, however, the facts are by no means so simple as this theory would assume. The least intensity that can be noticed is not fixed even for the same individual, and the number of units that can be noticed is also variable.

In consequence, this scheme, attractive as it is in theory, has never been and apparently cannot be applied in practice.

Weber's Law. — Out of the very large number of experiments devoted to these measurements, a law has developed that is of great interest. Very briefly, it has been found that the size of the just noticeable increment is not the same for all intensities, but increases with the absolute intensity of the stimulus, and bears a constant ratio to that intensity. Thus Weber found that if a weight of 32 ounces were lifted, it could be noted that 30 ounces was just less, while if 32 drachms were lifted, 30 drachms could just be noticed to be different. A difference of a fifteenth of the total weight could be noted whether the units were ounces or drachms. These relatively crude experiments have been repeated and improved upon by a number of later workers, Fechner in particular, and show the same general law. The fraction of the total intensity that may be just noticed varies from one sense to another, but holds with fair accuracy for the same sense. The values range from approximately $\frac{1}{100}$ for sight to one-third or one-fourth for smell. In giving these values, it should not be assumed that the just noticeable difference is absolutely constant even under constant objective and subjective conditions, or under conditions that are as nearly constant as can be obtained. Differences in the order in which stimuli to be compared are given, in the degrees of attention at different times, and in the way in which the suggestions that may be given unintentionally may work, all have an influence upon the determination of the

difference limen. In consequence, it is not often that two consecutive experiments will give the same result. All values given are averages obtained with the same individual, and where several values are given it is assumed that the two are extremes for the subjects used. Occasionally the values obtained from different observers will be averaged, but this is not at present regarded as advisable. The results are not to be regarded, as in physics, as constant values that are obscured by the varying conditions of observations, but as fundamental differences due to the differences between individuals.

Departures from Weber's Law. — It is also true that the fraction varies for the different absolute intensities. It is always greater for the extreme intensities, and even within what may be called the mean values, there is often a gradual change. The first fact can be seen in many of the simple phenomena of daily life. The increase in the least noticeable difference at maximum intensities is illustrated in the difficulty in reading when the sun is shining on the page, as the difficulty in reading in faint light illustrates the increase of the relative difference at the lower range of intensities. The relative amount of light reflected and absorbed is the same at all intensities, but the relative difference that may be discriminated is much greater at the extremes of absolute intensities. Were relative differences discernible with equal ease at all intensities, one could read as readily by moonlight as by electric light, and in the glare of the sun as well as in the shade.

The values that have been obtained in the more important senses range for vision from $\frac{1}{65}$ to $\frac{1}{195}$ for different

observers and different intensities. For hearing, Wien, using telephone tones, obtained a fraction of $\frac{1}{5}$ to $\frac{1}{8}$; for pressures, values have been obtained from $\frac{1}{10}$ to $\frac{1}{30}$, depending upon the part of the body stimulated. Lifted weights give a much smaller value than passive pressure, from $\frac{1}{20}$ to $\frac{1}{100}$, according to Biedermann and Lowit, according to Weber $\frac{1}{40}$. Taste, smell, and temperature, all offer difficulties in the technique, and the results are correspondingly unsatisfactory. The values of the fraction for these senses are generally given as ranging from $\frac{1}{3}$ to $\frac{1}{4}$. The results of the investigations of the least intensities that can be perceived, the absolute sensation limen, have also been determined for certain senses with a satisfactory degree of accuracy. For sight and sound the values can be given in terms of absolute units. Langley found that the eye was sensitive to light waves that exerted an energy of .00000003 erg. Wien found that the ear would respond to still smaller values: from .000004 erg for tones of 50 VD per second to .0000000000000005 erg for tones of 3200 VD per second. For pressure, the most reliable results are those given by von Frey, who worked with individual pressure spots. He found that the values were fairly constant for different spots, from .5 to 4 grams per square millimetre of surface stimulated. Values obtained for other senses have relatively little meaning, as they cannot be stated in terms of energy.

Theories of Weber's Law. — It can be asserted, then, that within limits Weber's law holds. Differences in two stimuli are noticed more easily when the absolute stimuli are low than when they are high, and the addition

that can just be appreciated is a constant fraction of the stimulus already present. The explanation of this law falls into three groups. Wundt holds that the law has a purely mental basis, that it is but one expression of the general law of relativity; all things are estimated in terms of other things that may be in consciousness at the moment. This is merely a restatement of the law rather than an explanation. Fechner regarded the law as an expression of the general relation between body and mind. These were two phases of a single substance for him, like the inside and outside of a circle, and in some way not made clear, stimuli that increase in a geometrical ratio produce an increase in mind in an arithmetical ratio. A third theory, developed in large degree by G. E. Müller, explains the law as due to the loss in intensity that a nerve impulse undergoes in passing through the nervous system itself. That such a loss does take place is suggested by the experiments of Waller with the optic nerve and retina of a frog. The current of action of the nerve excited by different intensities of light upon the retina was measured and it was found that the current of action was related to the intensities of stimulus in the arithmetical-geometrical ratio. Müller asserts that the more intense the stimulus, the more opposition is offered to its passage through the nervous system, and in consequence the more is lost, a smaller proportion reaches the brain. If the amount lost — and so the amount retained — is proportional to the absolute intensity of the stimulus, the demands of Weber's law are satisfied. Ebbinghaus has suggested that this increased loss can be explained on the assump-

tion that there are in the nerve chemical substances which decompose with different degrees of difficulty. The less intense stimuli use up the more readily decomposable elements, and hence produce a relatively great effect on consciousness, and the stimulus must exhaust an increasingly greater amount of energy in affecting the components next higher in the degree of difficulty of decomposition. Whatever the detailed explanations, the facts available indicate that the law is due to the increasing resistance offered in the nervous system to the transmission of the more intense nerve impulses, that the explanation is physiological rather than psychophysical or purely psychological.[1]

[1] Titchener, Manual of Psychology, Instructor's Manual. Quantitative.

CHAPTER VI

IMAGES AND THE LAWS OF CENTRALLY AROUSED SENSATIONS

Not all of the material of knowledge comes directly from the sense organs. Memory, imagination, and similar processes have an equal part in our mental life. From the objective point of view, behavior is controlled by the past as well as by the present stimuli. Provisionally we may treat these processes as if they were on the same level as sensations. We may think of them as composed of definite pictures that return as wholes or are recompounded of elements derived from the senses. Put in this form, our present problem is to determine their components, and to discover how they are retained and the laws that govern their reappearance. The primary qualities are like sensations. No absolutely new qualities can be imagined. Speaking generally, the qualities of memory and imagination are the qualities of sensation. It is possible to go farther and assert that if one is to have images, one must at some time have had sensations of the corresponding quality. Individuals blind from birth cannot imagine colors; even the color blind cannot picture the colors which they cannot see. The same holds for all other senses. This has led to the general acceptance in modern times of the statement that all images are derived primarily

from sensations. This simplifies our discussion to one of asking how the original impressions are retained, how they may be rearoused as occasion demands, and how their qualities differ from those of sensation.

The Nature of Retention. — The question how memories are retained must be preceded by asking where they are retained. Two possibilities have been suggested in the history of the science: one that they are retained in mind or as mental states, the other that they are held in the nervous system. The latter is at present generally accepted. The theoretical objection to thinking of memories as being retained as mental states is that mental states are by definition conscious, while there is no awareness of memories until they are revived. The individual cannot tell that he has a memory, has no awareness of the amount of his knowledge, until he tests it by trying to call up particular facts. On the positive side, the evidence that remembering is in some way dependent upon the nervous system comes from pathology. Numerous cases present themselves in which loss of memory is one of the prominent symptoms, and these usually show, on examination of the brain, injuries of portions of the cortex. Destruction of the area corresponding to a sense brings with it loss of the corresponding memories; destruction of neighboring areas or of paths of connection with other portions of the cortex also destroys or impairs the effectiveness of recall of the images. Studies in mental pathology have convinced psychologists that memory processes are closely dependent upon the nervous system.

How memories are retained offers more room for

discussion. Various theories have been suggested, from the crude theory of the Greeks that memories were imprinted on the brain or soul as the impression of the seal upon wax, to the scarcely less crude anatomical theory that each idea had a cell in the brain in which it might be stored. At present the tendency is to find analogies that shall be within the known possibilities of the nervous system and not to make the explanation more specific than the known facts warrant. The explanation is usually in terms of function, of what the nervous system does when it remembers, rather than of how it holds the memories. Hering was among the first of the modern writers to suggest this method of approach, in stating that memory is a universal property of matter. Any change that may be suffered by any substance tends to persist. Garments wrinkle where they have been often creased; *i.e.* the folds tend to persist. Scars on the skin, even nail holes in boards, are for him memories, effects left on the substance by changes it has undergone. In the organic world similar facts are particularly striking. The physician constantly finds that any injury or disease of a tissue leaves an effect, — it is weakened for a considerable time. On the other side, exercise of a muscle strengthens it.

Retention and Habit. — Habit is the best known expression of this fact in connection with the nervous system. As was said in the earlier chapter, habit may be stated in its most general form to be a change induced in a tissue as a result of doing something. This leaves a tendency to do that same thing more easily. Signs of habit formation may be seen even in the unicellular

organisms. A Stentor responds differently after a series of responses have failed to give a pleasant result; and after the new variation has been repeated several times, that will tend to persist for some time, — will become a habit. In the higher organisms one may think of both habit formation and of memory as due to persistence of changes wrought in the nervous system by its action. Habits are regarded as due to changes in the synapses of the nervous system. Neurones that have acted together once tend to act together again; nervous impulses spread from the one first active to the others, owing to the lessened resistance of the synapses that intervene. From the standpoint of Hering, memory in its essentials has the same basis. It is primarily the capacity of retaining the effects of one action of the nervous system in a form that shall make probable its repetition at some time in the future, rather than the retaining of some static thing, or impression, or idea. Speaking generally, after an object has once been seen, a tendency persists for the neurones involved to act in the same way again, and this tendency leads to the revival of the image on suitable occasions. The nervous system may be regarded as acting in a certain way at the time of perception, and of repeating approximately the same action at some later time. What is retained is probably, as in habit, a tendency for certain elements of the nervous system to act together. This tendency is due to a lessening of the resistance at the synapses between the neurones involved in the response. Those portions of the cortex that are concerned become connected as a unitary whole,

and when one part is reëxcited, the others are rearoused. What is left is merely the physical or chemical change in the neurones. Where this change may take place can be determined only by indirect means from a study of diseased conditions. Present evidence makes it probable that the most important part of the change is found in the sensory areas or in the immediately adjoining association areas, although no portion of the original nervous tract can be absolutely excluded from consideration.

After-image, Memory After-image, and Memory Image. — One may also trace an analogy between memory and simpler forms of retention or prolongation of activity in the sense organ. In vision, gradations may be traced between the after-image and the more extended memory image. If one look for a moment at a bright color, it will continue to be seen for a fraction of a second after the impression has been removed. Even faint objects leave another kind of image, clearer and of longer duration, which does not move with the eyes and may be shown to have its seat in the cortex. This process is known as the primary memory, and is probably partly identical with what Fechner called the memory after-image. It is sufficiently distinct to be used for all purposes in place of the actual sensation, and is for many purposes even more effective than the sensation. It may be regarded as due to a persistence of the activity of the cortical elements involved in sensation in just the same way that the after-image is a continuation of the action of the retinal elements. They possess an even greater inertia and so act for a longer time.

Miss Martin has suggested on the basis of Fechner's description and her own observations that Fechner's memory after-image was a composite of the after-image and this primary memory; other authorities have for the most part identified them. Our needs are satisfied with the recognition that both the after-image and primary memory exist and are due to practically the same conditions; one is a persistence of the visual processes in the retina, the other a persistence of nervous action in the cortex. A memory, in the same series, would be merely the reinstatement of the primary memory image after the lapse of a longer or shorter period. The same nervous elements may be assumed to be active at the moment of recall as in the former case, but they have ceased to act or at least ceased to produce conscious processes for a longer or shorter time, and then the activity is in some way reinstated. The three, after-image, memory after-image, and memory image, all exhibit many of the same laws and may be regarded as succeeding steps in the same series. The after-image is the persistence of the effect in the sense organ; the primary memory, a persistence of the activity of cells in the cortex; memory, a reinstatement of the activity in the cells of the cortex involved in the primary memory.

Reproduction. — Granted the retention of a tendency to act again in a way once acted, it is next in order to ask how or when this reinstatement of the activity may take place. Two occasions are ordinarily recognized at present, the perseverative tendency and association. The former is simpler, although less frequent

and less generally accepted. It was suggested by Müller and Pilzecker that, when an impression has been made, the nerve cells impressed continue active for a time, and in consequence the corresponding ideas are likely to force their way into consciousness when nothing else offers, or to combine with other processes active at the same time in the production of more complex processes. This they call perseveration. Instances mentioned are the reappearance of words that have been heard or spoken just before but have no noticeable connection with the course of thought; the tendency of tunes to 'run in the head'; of complicated practical problems to keep returning to mind on all occasions, etc. This tendency seems to decrease rather quickly at first, but some slight effect is supposed to persist for hours, and when the original event is interesting or the impression strong, may last for several days. It is assumed that the activity of the nerve cells is continuous, but that the effect of their activity rises to consciousness only now and again. While the perseveration tendency itself is unquestioned, it is a matter of dispute how long it continues and whether the reappearances after a little time are due to that or to associations that have not been noticed.

Laws of Association. — Association as an explanation of recall can be traced back to Aristotle in fairly accurate formulation, and suggestions of it are found in still earlier writers. In some form or other it is recognized by all. In general, this doctrine asserts that all reproduction of ideas is determined by the connections that have been formed at some time in the past. Con-

versely, mental processes that have once been in consciousness together, tend to return together. An empirical study of learning shows that words, nonsense syllables, or objects shown together or in immediate succession tend to become connected and when one is presented again, the other also reappears. Learning the name of a new object, connecting a person with a place where he has been seen, all rote learning provide instances of this sort. On the physiological side, it may be said that all learning, all experience, is of things in their connections, and that all return is through the connections formed between neurones at the instant of learning. When a group of neurones was active at the time of the original experience, paths of connection were formed, synapses were opened between them, and, later, when any element of the complex is aroused in any way, the impulse tends to spread over the partially open synapses to the other elements of the whole. Association has the same basis as habit, but need not end in a muscular response. As was said in the beginning of the chapter, all learning is like habit formation; all learning is dependent upon formation of connections between neurones, — nothing can be learned in isolation. In consequence, association is at once the fundamental fact in learning, in retention, and in recall. Learning is always the formation of connections between neurones; retention is always the persistence of the connection, or the partial openness of synapses which permits an impression to pass from one to the other of the connected elements; recall is the rearousal of the whole complex by some one of the elements that

may be stimulated from the outside world, directly or indirectly.

While from the standpoint of learning it may be asserted with assurance that impressions presented together tend to return together, more complication appears when one attempts to determine what it is that has brought any particular old experience to mind. Any idea that returns has almost always been associated with several, often with many experiences, and it is difficult to say which one has been responsible for its recall; in fact, usually a number of factors more or less remote coöperate in the recall. Similarly, if some one familiar experience be presented, it is not possible to say with certainty what idea will be recalled by it. One may study the tendencies to recall by presenting a number of words to a subject, and letting him speak the first word that comes to mind. If the same list of words be presented to a number of persons of approximately the same earlier experience, it is found that a large number of the responses will be common to all. Kent and Rosanoff secured the associations called out in a thousand people to each of one hundred words and found that the number of common words was very large. Thus to man, 394 responded woman, 99 male, 30 strength, 44 boy, 30 person, etc.; to mountain, 246 responded high, 184 hill, 73 height, 90 valley; to soft, 365 responded hard, 53 pillow, 34 easy, etc. If one will permit the train of ideas to wander uncontrolled for five seconds and then write down the ideas that present themselves, similar connections can be traced. The connections have from time immemorial been classified under four

heads, — contiguity, succession, similarity, and contrast. In our list of words it will be seen that all the connections given can be traced to one of these groups. Soft and hard, mountain and valley, man and woman, may be regarded as contrasting; hill and mountain, soft and easy, man and male, may be regarded as similar; soft and pillow, high and mountain, man and strength, as connected through verbal succession or by contiguity of the objects.

The Nervous Basis of Association. — It should be noted that this is always a classification of the connections after they have been made, is made after rather than before the fact, is a classification of the relation the ideas hold to each other, rather than a statement of the causes of recall. Even so far as it holds, it is not altogether unambiguous. Mountain and valley are contiguous as well as contrasting, man and woman, as all contrasting things must be, are in some degree similar; they also are frequently found together and the words have been repeated in succession.

For the real cause of arousal, we must turn again to the neurones that are involved in the activity. They can be connected in only one way, by the opening of the synapse between the nervous elements involved. The cause of the permeability of the synapses may be made the correlate of either contiguity or of succession. The former corresponds directly to the law of habit, —two elements active together tend to act together from that time on. Succession has practically the same explanation. The second neurone begins to act before the

first ceases its activity, and so the two actions of the neurones are simultaneous. If similarity is to be explained in physiological terms, it must be reduced to partial identity. What one calls an idea is always complex and may be pictured as corresponding to the action of a number of neurones. In what is classified as association by similarity, a mass of neurones corresponding to the first idea are active, and as time goes on parts of the group cease to be active, — only one group of those corresponding to the part of the idea most attended to at the moment persists in its activity, and from this, new neurones that correspond to the elements of the second idea are excited by virtue of their previous connections with the persisting portions of the first. On the side of consciousness, many ideas in the popular use of the term are complexes of experiences, complexes of sensations; probably also the action of many different neurones is involved in their appearance. In the recall of any complex idea, these different elements probably enter into many different combinations, and the effective connections are between the elements, not between the larger masses. Thus when an idea recalls another similar one, the similarity is due to some common element, and this common element may be regarded as persisting from one idea to the other. In one idea all disappears but the elements that are common; these persist and gather about them by association the other elements which with them may be regarded as constituting the new idea. When the ideas are classified afterwards, they are seen to be similar, the association is said to be by similarity, but the effective forces have been the

waning of certain elements of the first and the excitation of others by those remaining. Association by similarity is really through partial identity, and the identical element furnishes the bond of connection.

Not only must we limit the application of the doctrine of associations by the assertion that it is the neurones at the basis of the elements of ideas that are associated rather than the ideas themselves, but we must also recognize that associations give only the possibility of recall, and that selection must be made between the possibilities by more remote factors. Most neurones or sensory elements have been connected at different times with several other elements, and may be regarded as having a tendency, whenever any one is aroused in any way, to rearouse each of the others with which it has been connected. Which of the possible elements shall be aroused is determined by the same elements that control attention. A discussion of these may be postponed to the next chapter. For the present we may say that the return of an experience or the renewal of an excitation of a group of neurones depends in some degree upon the continued activity (perseveration) of the elements in question, an activity that lasts for a relatively short time, but for the most part depends upon the fact that when any two groups of nerve cells have been active together at any time and one is reëxcited, that excitation tends to rearouse its earlier associates.

The Qualities of Centrally Aroused Sensations. — These memory processes may be studied, not merely to determine the ways in which they are retained and the laws of their revival, but also with reference to the

actual content that they offer. One may study the materials of the remembered impressions just as one may study the qualities that are derived from the external senses to determine the elements that make them up or, more profitably, to compare them with the qualities of the immediate sensations.

Most untrained individuals do not notice the content of their minds as they recall; they are content to know that they recall an object and can describe it. Others who have had training in introspection find that they do not have images; they have no definite mental content when they recall an object but have merely the certainty that they have seen it before. Our present problem is to determine what is in mind when the object is recalled. If one is attempting to recall a desert or a mountain landscape seen years ago, *e.g.*, one may either repeat words that have been associated with the experience without any definite picture of the landscape, one may have fleeting bits of yellow sand or snow-covered peaks with many vacant areas or dark gray regions with no definite pictures, or one may have a clear and distinct picture from which one may paint or describe many if not all of the details. Our question at present is how these images differ from individual to individual and how they resemble, and how they differ from, actual sensations.

Two methods of investigation have been applied to the solution of this problem. The first of these was used by Külpe[1] in an experiment to determine how one might distinguish faint sensations from imagined or remem-

[1] Külpe, Philosophische Studien, vol. 19, pp. 508–556.

bered experiences. Faint sensations were chosen because memories are generally believed to be fainter than sensations. Investigators were placed in a dark room where faint lights of different colors could be thrown upon the wall. At a given signal, the observers were asked to say whether a light was seen and then, if it were seen, to say whether it was objective or merely imagined. At times a light was really shown, at others not. In most cases at the signal the observers either saw or imagined a color. After the report had been given, an attempt was made to determine what differences were used as a basis of deciding whether the image was objective or subjective. In this observers varied. All agreed that there was a constant difference in quality, the subjective processes were more transparent, were net-like or clouded. The objective seemed brighter, they entered and left consciousness suddenly and as wholes, had a more definite form, were clearer, and were given a more definite position in space. They were distinguished also by the more active tests, — that objective colors left an after-image, were stationary when the eyes moved, and vanished on closing the eyes, — while the reverse held in each particular for the subjective processes. In addition there were individual peculiarities from man to man; *e.g.*, greater duration was given by one as characteristic of sensation and by another as characteristic of the image. The results of this investigation indicate that there are a few characteristically different qualities that attach to the centrally aroused processes and serve to distinguish them from the more objective experiences.

The Projection of the Memory Image. — Another investigation gives approximately the same results by a method even more striking. Miss Martin[1] found that it was possible after a little practice to project a memory image outward into space, where it might be more readily compared with sensations. The different location of images and sensations serves in our ordinary experience as one criterion of distinguishing them. We project sensations where the object is assumed to be in the outside world, while the memory or imagination either is given an indefinite place, is projected backward within the head, or possibly referred to the place where it actually is, but usually not out upon the surface that is actually presented to the eyes. Miss Martin's observers found it possible to bring the image and the object side by side. When the difference in projection that ordinarily exists between images and perceptions had thus been removed, it was found that there were still characteristic differences between the two in their coloring, in definiteness of contours, in clearness, intensity, and stability. The sensations had the advantage in each of these respects. One other characteristic is the relation to the movements of the eyes. While in these experiments the images did not always move with the eyes, there was always a tendency to movement when the eyes moved that could be avoided only by considerable strain. All of these criteria for distinguishing between the two agree with those indicated by Külpe's investigation. One other presents itself for certain

[1] Martin, Die Projektionsmethode und die Lokalisation visueller und anderer Vorstellungsbilder.

observers, — that is the tendency to see the images in front of the background of sensory objects which may be present. The background may be seen through them as through a veil. In general it is noticed that sensory impressions interfere with the perception of other objects, while images do not thus interfere.

Individuals who possess definite images, then, have also characteristic means of distinguishing them from the sensations, — they show differences from the sensory experiences constant enough to prevent one from being mistaken for the other. Individuals may not notice the characteristics that serve to distinguish images from sensations. In fact, few do until they have been called to their attention, but the differences serve to ascribe the process to the world of things if of one character, or to memory or imagination if of another character. In addition to these differences in the mental content, the connections in which the experiences present themselves also play a part in determining whether an experience is objective or subjective. If the object or event follows naturally upon other events that are recognized as objective, if the sound of steps is heard outside, the bell rings, a servant answers and a moment later a friend enters the room, there is no question of the objectivity of the experience. If, on the other hand, a letter in a familiar handwriting is seen and then an image of the friend who wrote the letter appears, there is no doubt that the image is subjective. One event fits into the objective setting, the other into the memory picture, and in consequence the one is assigned to the one group, the other to the other.

This placing of the mental process in terms of antecedent events and the setting is undoubtedly the most important of the factors that lead us to discriminate between the objective and the subjective. Again this operation is not noticed for itself. One knows at once that one sees an object in the one case and that one merely remembers it in the other. The method of remembering is no more noticed than is the method of perceiving.

One may in a sense and for most individuals parallel the sensations which are regarded as constituting the raw material of our external experiences by a series of images or centrally aroused sensations which constitute the materials out of which the things that appear in memory, imagination, and reason are composed, 'the stuff of which dreams are made.' These are retained in the central nervous system and rearoused by stimuli that have been connected with them in the past and by other ideas that have been experienced with them. It should be noted that the memory images are usually not so complete as the sense presentations, that even the clearest of them have large gaps due either to imperfect attention at the time of perception or to lack of interest in some phase at the moment of recall. Also much of our memory and thinking is not in definite reproductions or constructions of the objects, but is very sketchy. It is very frequently in words or in some other symbol that represents or means the thing rather than constitutes it. This must be considered in detail later on; it is mentioned now merely as indicating that our inner mental life is not to be described completely in

terms of definite images. Even where centrally aroused sensations are most definite, the number of qualities is less than the number that may be found in immediate sensation. Of the hundreds of grays the unpractised man cannot recall more than a dozen. Relatively few elements in memory must be made to do duty for the vast number of sensation qualities.

Memory Types. — In our discussion of the qualities of the centrally aroused processes, it must be noticed not only that the quality of the memory element is not the same as the quality of the thing represented, but the way in which anything is recalled differs greatly from individual to individual. We all think of the same things, but probably no two of us have in mind exactly the same images when we think of the object. The main differences in representing objects and events can be most readily stated in terms of the sense organ or the sense material that is emphasized or drawn upon by the individual. The students of mental disturbance, Charcot among the first, noticed that certain men would make predominant use of the visual memories, others of the motor, others again of the auditory. Still later Galton [1] made a careful examination of the way a number of individuals recalled the breakfast table, with the result that some were found who would merely recall the way the dishes and the people at the table looked, others could remember the sounds of words and the rattle of the utensils, still others could remember only how their own various movements felt as they were made. More rare were the individuals who could remember

[1] Galton, Inquiries into Human Faculties.

the odors and tastes of the food, and these memories were usually indistinct and subordinate. Galton also distinguished the verbal type, individuals who recalled everything in words, either as words seen, or words heard, or words as they would be felt in the vocal organs at the time they were uttered. In older individuals, particularly men of science and others who indulged much in abstract thought, the verbal tended to predominate over the more concrete imagery.

Galton or certain of his expositors leave the impression that an individual is likely to have one type to the exclusion or at the expense of all others. Certain of the later writers have still more exaggerated this assertion of the mutual exclusiveness of types. Stricker, for instance, has argued that every one must be of the motor type, and further that the recall consists in nothing more than the reinstatement, in some slight degree, of the movements made on a large scale at the time of the original experience. He challenges any one to think the sound of *o* with closed lips, and regards failure to do so as proof of his contention that all thinking is in terms of a reinstatement of some movement. Most recent investigators, however, incline to the view that while imagery is much more restricted than sensation, that most individuals have more than one type, many two or more, in approximately the same degree. These individuals will use the type of imagery most suited to the problem in hand. If, *e.g.*, one both paints and composes music, one would plan a picture in visual images and compose in auditory terms. While one or more types may be lacking in most individuals, and

one or more be preferred, the sharp classification into visual, auditory, etc., seems rather too rigid to harmonize with the facts. Miss Fernald finds three main types, — one in which the different images are used with approximately equal readiness, one predominantly visual and motor, and a third auditory and motor.

Much remains to be done on many phases of the study, particularly from the statistical side. At present the data as to the number of each type, and the degree of difference between the types, are deficient in very many respects. We do not know on any very trustworthy experimental basis the relative proportions of the different types, and their distribution with reference to professions or general capacities. Lacking this, it is also not possible to reach any conclusion as to how the differences are brought about. Evidence may be adduced by a few cases in favor of an hereditary predisposition. Dodge, who is almost altogether without auditory imagery, reports that his parents had the same lack. The inheritance of musical ability, which in all probability depends upon the possession of auditory imagery, may also be cited as evidence of an hereditary tendency. On the other side, training has been shown in several individual cases to have exerted an influence in changing the memory type. Particularly with school children, it is found that they can be trained to considerable facility in types of imagination in which they possess no natural skill. Even in adults long practice gives results in the development of new forms of imagery. A student who cannot spell because he cannot see the words in his mind's eye can by repeated effort bring

himself to visualize the words, with some degree of improvement on the practical side. It does not follow that spelling is absolutely dependent upon the possession of the visual type. It seems, then, that both heredity and training may play a part in determining the mental type, — certainly training may change what is given by heredity.

Synæsthesia. — A curious occasional phenomenon is found in the close connection in certain individuals between objects or sensations of different senses. It is most frequent in the association of sounds with colors, — a sound tends to arouse at once certain colors that are characteristic of the sound. Numerous cases have been recorded in which letters have colors attached: *a* is pink, *o* green, etc., and words either will have a color of their own, or will take on the color of the letters that make them up. Several cases have been reported, too, in which musicians will have colors aroused by certain tones or tone combinations, and these may seem to be essential components of the tone effects. Thus Myers reports that Scriabin, the Russian composer, had a different color for the different keys. The major keys of C, D, B, and F♯ have the colors of red, orange-yellow, blue, and violet, respectively, and the effects are so strong that he desired to have his compositions rendered to the accompaniment of colored lights that should flood the hall from concealed lamps. In another striking case odors were associated with colors; in fact, were often only perceived through their color associations.

Two theories have been held to account for the phenomenon: one that the connections have been made

through association, the other that it is fundamental and perhaps due to the fact that there is some common feeling or other element which serves to connect the two sensory components. The second theory if true must admit that individuals who possess this idiosyncrasy seldom agree as to the colors that shall be associated with a particular tone. Each person who has the idiosyncrasy feels that it is universal and necessary. The association theory is as yet equally unproven, although a few characteristic peculiarities suggest that colors may be taken from old habits. Thus in three sisters whom I investigated, one of the few correspondences was that *j* was said to have a gritty brown color to all three, an obvious connection with jug. How far heredity plays a part, how far there may be more fundamental common characteristics between the sensations connected, and how far the phenomenon may be merely the result of early associations is still largely a matter of conjecture.

In brief, the qualities of centrally excited processes are the same as the qualities of sensations, a little less numerous, with not quite the same distinctness, but with no new qualities added. These impressions are recalled through the laws of association not so very different from the laws of habit, and are woven together in new patterns to give features of remembered events that suit the purpose of the moment, or to make new constructions of imagination or reason. As is to be seen in the next chapter, these constructions are subordinate to more general controls in the same degree and by the same laws as sensations.

CHAPTER VII

ATTENTION AND SELECTION

No study of the mental life of man can be content with an enumeration of the sensations, peripherally and centrally aroused, and with the laws of association. These may be said to give the materials of mind, but to understand either action or consciousness much more is required. Everywhere in mental life we find signs of spontaneity, indications that the effects of stimuli and the laws of association do not alone suffice to explain all. The individual selects from among the stimuli, seems to increase the effect of one at the expense of the others. On the active side one stimulus is more likely to produce a response than the others; in consciousness it becomes clearer, and lasts longer. These effects are ascribed to attention. Attention is not a faculty; it is merely a name that has been given to the fact that there is selection, that the selected stimulus becomes more effective, more prominent in consciousness, and more likely to cause movements, and also at times to the conditions of these changes.

The fact of attention is apparent to all and at all times. As one looks out over a landscape, one feature after another is noticed; as one sits at the study table working, the noise of the street, and memories of all kinds, will

from time to time intrude themselves and crowd out the material that is coming in from the page of the book, even if the eyes still wander along the lines of print and all the other physical conditions of reading are unchanged. In both cases the mental content varies because of changes within rather than without. A slight observation of the course of mental processes shows that most of the changes are subjective rather than merely physical. We are conscious at any time of only a fraction of the things that might be observed. Many sensory experiences pass unnoticed unless we look for them particularly. The vast majority of objects presenting themselves to the eyes are not seen, and many of the sounds that fall upon the ear are not heard. We select only the few that appeal to us at the moment.

Does Attention Increase the Intensity of Sensation? — To begin with the change in content with attention, we must ask what this change is. The answer is to be found in the observation of one's own state as one attends, rather than in a verbal description. Certain it is that the object or event attended to becomes in every way more important for consciousness; it stands out above the others at the moment, is also more likely to be remembered and to start new trains of thought. The character of the change can be given only by comparing it with other known changes and indicating the similarities and differences between them. In many respects it is like an increase in intensity. Increase in the intensity of a physical stimulus also makes it more likely to enter consciousness, increases the probability of recall, and quickens reaction to it. That they are not identical is evident

from the fact that we never mistake one for another. On the other hand, it is certain that the two changes have much the same practical effects; both attention and intensity make the experience more important for consciousness. Attention also produces an increased clearness of outline. In this respect it has an effect similar to that due to increased closeness of the nerve terminations.

Consciousness as a whole has been likened by Wundt to the field of vision. There is a point of clearest vision in the centre where the cones are very close together, and a gradually decreasing clearness as one passes outward to the circumference. The point of maximum attention corresponds to the fovea in the field of vision, the other regions of consciousness to the periphery. Attention may wander over the field of consciousness in much the same way that the eye wanders over the field of vision. The common characteristic of foveal vision and attention is the increased clearness that comes in both cases. As a result, contours and differences in intensity between parts are better discriminated. Temporal effects of attending to a sensation have been noted in hastening its entrance and in keeping it a little longer in consciousness. All these differences would increase the importance of the impression attended to as compared with one that is not attended to.

The Distribution of Clearness. — Much discussion has arisen in the last few years among the people who would make clearness the primary characteristic of the attentive consciousness, as to the way in which clearness is distributed over the field of consciousness. Titchener

regards clearness as one of the fundamental attributes of consciousness, on the same level with quality or intensity. He first asserted that there are at any moment in consciousness but two degrees of clearness, — the centre upon which attention is fixed and the hazy background. This first statement was softened in large measure, however, by the admission that there might be differences in clearness in both upper and lower levels, separated by a marked break in the degree of clearness between the two levels. Under the criticism of Wirth, who asserted that consciousness grades off gradually from the clearest point to the most obscure, Titchener renewed his investigation of the question, and found that there was a difference between individuals in this respect, that certain people belonged to the two-level type, others had a number of different levels or even approached the gradual passage from maximum to minimum clearness that Wundt had described as the universal type.

Attention as Selection. — The process of selection requires less description although in its ramifications it probably takes more different forms and is more important in its effects upon consciousness. In part, selection is effected by increasing the clearness of the content, an element obscure at one moment becomes clear at the next; in part, the process selected rises from complete obscurity to a dominating place in consciousness, a possible content is made actual at one stroke. We are concerned with it primarily in connection with the admission of certain stimuli, — with the fact that, with attention, a stimulus that has been present but ineffective suddenly rises to a prominent place. In later discussions it will be

seen that the fact of selection is of fundamental importance; that we select not merely stimuli, but that we select ideas from among those made possible by association, and through ideas we reach decisions and select acts. It will be found, too, that many of the same principles, many of the same conditions, are involved in the selection of these higher or more complicated processes that are involved in the simpler operations we are dealing with here.

Motor Concomitants of Attention. — If we turn from function to subordinate features of attention, we find that a characteristic quality is given the experience of attending, both for the one attending and the observer, by its accompanying movements. These are of varied sorts and degrees. Most important in practice are the actions involved in the accommodation of the sense organs. As one attends, the organ adjusts itself to give the best possible conditions for observation. The eye at once turns so that the object falls upon the fovea, the lens without further thought is given the right curvature, the eye is in consequence focussed for the distance of the object, and the two eyes are converged to permit both to see it with the fovea. Each of these adjustments is made without specific intention and usually without knowledge that they have been or are being made. One cannot adjust the lens, contract the ciliary muscle, by direct impulse. The only way to move the muscle is by changing attention. If one attends to a distant object, the muscle relaxes; if one attends to a near object closely, it contracts, but this is the only way that it can be made to act. The same statement holds in less degree of turning and converging the eyes. The movement

follows at once upon attention and is always a result of attending. In the other senses, the adjustments of the sense organs are less striking, although still present. The head is turned toward the source of sound to increase the certainty of receiving the tones. This is particularly noticeable if one ear be defective. The head will then be turned to one side when listening to receive as much as possible of what is being said. The muscles in the middle ear probably have a protective function only, and play little part in attentive listening. When one is asked if one notices smoke, sniffing follows automatically to bring as much air as possible to and through the nostrils. Similarly, when a cook passes critical judgment upon a product of his art, the substance is pressed more closely against the tongue by bringing the tongue against the roof of the mouth. In feeling a surface the hands are kept in motion that the slighter irregularities may be noticed. In the blind this frequently develops into a series of slight movements of the finger tips made automatically and almost unconsciously. Comparing weights calls out similar lifting movements of the whole arm. Each sense, then, has a series of accommodatory movements that make the sensation more adequate and complete, movements that come without thought, are an immediate outcome of attending, of the desire to know more about the object in which one is interested.

Mimetic Movements. — Another characteristic group of movements is carried out by the voluntary muscles of all parts of the body, which depend for their character upon the nature of the thing attended to. Every movement that is absorbing or that is watched atten-

tively tends to induce or be accompanied by similar movements on the part of the onlooker. Thus if one is watching an athletic contest closely, it is probable that one will make slight movements in imitation of the contestants. This tendency to act out ideas explains many of the cases of mind reading and similar processes that approach the occult. Slight movements made without the knowledge or intention of the one and interpreted without the knowledge of the other serve as a basis for the communication. The capacity for interpreting these slight unconscious movements is found in animals as well as in man. The feats of "*Kluge Hans*" and the Elberfeld horses who seemed to do sums and perform other wonders were found on closer examination to depend in part upon noticing signals from the trainers which were given without the knowledge of the trainers. Thus a horse, when given a sum on the board, would begin to stamp and continue the movements until the trainer indicated his satisfaction by some slight movement. These movements of the muscles of the face and of the bodily attitude constitute a large element in the appreciation of the mental attitude of a companion.

Diffuse Motor Discharges. — Still another large group of movements of the voluntary muscles accompanying attention is constituted by a contraction of most of the muscles of the body, due to a general discharge of impulses, a sort of overflow of motor excitations. As one attends strongly to any object one becomes tense, the brow wrinkles, the teeth are set, the fists may be clenched. The degree of tension increases with the degree of attention. One uses the feelings of strain subjectively as a

measure of the amount of attention, and one also regards the amount of contraction as a measure of the attention of another. It is not necessarily true that the efficiency of attention is measured accurately by the amount of contraction or of the resultant feeling of strain. These strains seem to be more pronounced when the resistance to be overcome is great, rather than when one is attending to the best advantage. But it is taken by the individual himself as an indication of the effort that he is exerting in attention, or of the effort that he is exerting in any field. Closely connected with these general contractions and accompanying marked attention is the inhibition of all movements. Some individuals must stop any movement they may be engaged in when they begin to attend, and in all there is checking of movements when attention becomes close. It can be noticed most clearly in an audience. When inattentive, there is always a sound made by the rustle of garments, by other movements, each in itself too slight to make a noticeable noise, but which in the sum produce a marked disturbance. As soon as the audience becomes attentive, all this stops and silence ensues. These inhibitions are of value in listening for faint sounds, and in many other sorts of attention they may increase the effectiveness of the sense in some degree. In time it has become habitual or even an instinctive accompaniment of all attending.

Changes in non-voluntary physiological processes also are present. These are perhaps most strikingly seen in the checking of respiration. As one attends, the breathing is checked. In a short period of profound attention the breath will be held and a sigh or deep inspiration will

follow relaxation. In longer periods the breathing first becomes quick and shallow; in still longer periods it is slower, but also more shallow than usual. Similarly, there are changes in the circulation. The heart beats more quickly, the blood vessels contract in the periphery and expand in the brain, the blood pressure rises, the pupils are dilated, tears are secreted which give the bright eye of interest. Each of these movements renders the organism more efficient. Holding the breath removes the noises of respiration that might interfere with faint sounds. The quicker heart beat and increased circulation in the brain prepare better for appreciation of the conditions, and for the activity that may follow. Attention, then, has widespread physical as well as mental effects. Accompanying increased appreciation of some one sensation or stimulus is a widespread irradiation of impulses to the muscles. These serve to increase bodily capacity, are an indication to an onlooker of attending and of the direction of attention. The sensations of strain which come from the contractions are assumed to measure the degree of attention. Most so-called mental tension is physical, due to these muscular contractions.

The Range of Attention. — One of the concrete problems that has been frequently discussed and most often measured in connection with attention is its range, the number of things that may be perceived at once. The experiments have been carried out by making very brief exposures of a number of objects, and asking an observer how many have been seen. The exposure is limited to a fifth of a second or less, a time which does

not permit any change of the attention or movement of the eye. Results agree that four or five objects may be seen at a single exposure. It is interesting to note, too, that the number of objects that may be seen is relatively independent of the size or complexity of the object. One dot, a group of three or more that makes some regular figure, a letter, or a small word are all seen with approximately the same ease. In fact, a short word is more certain to be recognized than a single letter. What constitutes a single object is fundamentally that it has been used or treated as a single thing, rather than its physical complexity. The number of auditory impressions is slightly greater than the visual, but they must of course be given in succession. Eight single ticks of a metronome may be appreciated when heard without rhythm, and when combined in a rhythm as many as 40, five groups of eight each, can be heard in a single unit. The experiments also make it probable that the objects are not really seen all at once but that they are counted after the exposure in the immediate memory or memory after-image. Careful examination of the process of attending to objects exposed for an instant shows that the real study of the object is made after the exposure. Impressions persist in the memory after-image with considerable vividness for some two seconds, long enough to count the five objects successively. One really, then, attends to but a single object at a time, but five successive acts of attention can be completed before the vivid memory image disappears.

Much the same problem has been raised with reference to how many processes may be carried on at once.

Occasionally one reads that some man has the capacity of doing two or more things at a time. Cæsar was said to dictate to several secretaries at once, and similar tales are told of others. Experiments have been carried on to test the point and all indicate that more than one process may be carried on at one time, but only provided one is sufficiently automatic to require no attention. Thus it is possible to write from dictation and do mental additions at the same time, and the time required for doing both will be less than the sum of the times for doing each separately. If it is attempted to do three things simultaneously or to do two things even one of which has not become pretty thoroughly automatic, more time is required to carry them on together than separately. Here again it seems that one can attend to but one thing at a time, although it is possible to start one series of activities and let it go on of itself while one attends to something else for a time. Attention changes from one to the other just often enough to keep the different processes going.

The Duration of Attention. — Another question of similar character is how long one may attend without a break. This question has been given different answers at different times, and the answer depends in part upon what is meant by the question. Speaking roughly, one may attend to the same general subject, may read a book, for example, for an indefinite period. Careful observation of the course of attention to faint stimuli shows that there are periods when they will be appreciated, other times when they cease to be noticed. Thus if one will listen to the ticking of a watch or the faint tone of a

telephone at a little distance, it will be noticed that the sound will be heard for an instant and then will disappear, and these alternations will continue as long as one listens. Similar fluctuations are present during the observation of faint visual stimuli. The explanation of these fluctuations has been variously given as due to fatigue in the sense organs, either of the muscles or of the sensory endings, to fatigue of the sensory regions in the cortex, or to changes in the blood supply to the cortex, and even to fluctuations of mental energy. The explanation cannot be regarded as completely agreed upon, although considerable evidence has been given in favor of all but the last theory. What is probably more truly a fluctuation of attention is seen if one will keep a record of the time that one can fix upon some single, simple object, a dot or a single tone. It will be seen that the single object will dominate consciousness for only a second at the most, then something in the neighborhood will crowd out the first, or a memory of some event of the past will intrude to exclude it. Between each of the other events attention will go back to the dot. The observer will be sure that the dot has been present all the time, but it will not have been attended to. It seems that one can attend strictly and definitely for a very short time, a second or so. In addition there are waves of increased effectiveness which come and go every six to ten seconds. These probably depend upon fluctuating physiological processes, central or peripheral. If one mean by attending to the same thing, attending to a general subject that contains changing elements, it is possible to attend for several hours — how long depends

upon the nature of the material, the strength of the observer, and other conditions that vary so much that they cannot be measured.

The Conditions of Attention. — The underlying causes or conditions of attention are to be found in the antecedents of the attending process in the individual himself and in the material that offers itself from the outside world. On the one hand, the individual attends because he is at the moment or in general of such a character that he must attend to the particular thing at the particular time; on the other hand, the characteristics of some stimulus and the general nature of the environment are such that he cannot avoid noticing it. If one asks why any individual notices any particular thing at any particular time, one will find the answer either in the nature of the environment or of the individual. The objective conditions may be found in the attributes of the stimuli that are attended to or, negatively, in the character of the other stimuli or the lack of all other stimuli. The attributes of the stimulus that are likely to arouse attention are its intensity, its size, its contrast with the surroundings. Loud sounds, bright lights, strong odors force themselves upon consciousness, while less intense stimuli fail to attract notice. Also contrast plays a part, as may be seen from the fact that a fairly bright light in the dark attracts as much attention as a brilliant light in full daylight, or a light footstep in the silence of the night as much as the automobile horn in the midst of a dense street traffic.

Another interesting fact in connection with objective factors is that change is an essential element in arousing

attention. One quickly becomes adapted to a continuous stimulus and ceases to notice it. A constant light passes unnoticed, but the shadow cast by the passing of a cloud at once intrudes upon consciousness. The slight noise of the burning gas drops into the background, and as Fechner pointed out, the miller is oblivious to the sound of his mill, but the slightest change induced by a defect will at once be observed. The cessation of the stimulus in this case is as effective as an increase in the sound. A clock that has been ticking unnoticed in the study will be noticed when it stops and the last few ticks will be heard, — sounds that would have had no effect upon consciousness had they not ceased. The decrease in the size of an object moving directly away from us attracts attention almost as certainly as does the increase in size due to its approach. Each of these effects of objective stimuli might be explained as due to the universal characteristics of man or to the inherited capacities of his nervous system. But since they are universal to all nervous systems it seems more simple to regard them of objective origin, than to assert that man's physical organism is adjusted through heredity to respond to stimuli possessing much energy and particularly to changes in the amount of energy affecting a sense organ.

Subjective Conditions. — More truly characteristic of the attention processes are the subjective conditions. We ordinarily think of attention as a free act by which we turn to one thing that it pleases us at the moment to notice and exclude all others. But frequently there is no conscious antecedent desire and, where there is, the

desires have their antecedents in the experience of the individual and these are to be regarded as the real conditions of his attending. Sometimes he knows that he desires to attend because of the antecedent experiences, more often he first finds himself attending and never knows why. If we examine the nature of attention in the light of the history of the individual, we may distinguish five different groups of subjective conditions. The first of these is the immediately preceding sensation. This can be best illustrated by hearing out overtones. If one is listening for an overtone in a note played on the piano, and has heard another note of the same pitch just before, he will distinguish it easily, while unless he has considerable training, without the aid of the note the overtone will certainly escape him. So if one desires to hear the first overtone of c on the piano, and will strike c' just before he strikes the c, he will notice the overtone, the c', without difficulty. Again an object just seen in a particular place will strike the eye when one seeks for it where previously it would not have been noticed. Very much the same statements may be made of the idea in mind. If one can call up a definite image of what is to be seen, the corresponding object will be noticed. It is probable that the skill of the practiced observer in hearing overtones is due to the fact that he can recall accurately the tone that he is to hear. This definite image replaces the sensation in its effect of making the overtone come into mind. Similarly, in a puzzle picture, to recall the concealed face in its actual place is a guarantee that the image will be recognized when one looks a second time. The image definitely recalled serves to aid the

entrance of the corresponding percept, in the same way as does the immediately preceding sensation.

Purpose or Mental Attitude. — Most important and striking of these subjective conditions is the influence of a factor that is variously designated the intention, the purpose, or the question in mind at the moment. When one has the intention of seeing a particular thing, that thing will come to consciousness. If one suggests that you look for a cell in the field of a microscope, the probability that you will see it is thereby increased. In daily life this purpose is the determining factor in all observation. One sees or hears only what one desires to hear, or what harmonizes with the intention. All that does not harmonize with that purpose, unless especially favored by objective conditions or other more general subjective conditions, might as well not have been offered to the senses. If one is interested in what an individual is saying, one will not notice his accent no matter how unusual, and if one is a phonetician and intent on the study of the peculiarities of speech, the meaning may be altogether lost. One does not notice the wall paper in a room unless the pattern is striking or one is deciding on wall paper for one's self and so has that as a dominant purpose at the time. Some objects that have been under one's eyes for years may never have been noticed unless some purpose made it desirable. To use a familiar instance, the reader cannot say without looking whether the four on his watch is iv, 4, or iiii, in spite of the number of times it has been looked at. One looks to learn the time, not to see how the numerals are printed, and sees just what one looks for and nothing else. This is typical of most

observation. Man is blind to what does not correspond to his momentary purpose.

This purpose or mental attitude may be aroused, either from without or from within. From without it may be due to a question asked by another, or by some task that has been set, or problem that has been raised by one in authority. From within, the purpose usually arises by a suggestion from something that has been seen. Something external or internal starts a train of associations. That raises a question about an object present, and one looks to the object for an answer. The answer to the first question suggests another problem, and thus a train of associations in the series of questions leads to one observation after another. Observation is most frequently the result of a series of problems self-set for solution. When one gets the problem or the question, finding the answer is relatively easy. Without the problem, observation is indiscriminate and relatively unprofitable. In this sense thought usually precedes observation, but the thought itself grows out of preceding observation, and so both are to be regarded as parts of a continuous progression in which each thought suggests attention, and the results of each attention, a new thought in a succession broken finally by the irruption of an intense stimulus or the necessities of the daily life, and this in turn starts a new series of questions.

Education and Attention. — A number of more remote conditions also aid in preparing an individual to attend in a given way at any moment. First of these is the earlier training and previous experience. This works in two ways: in the first place, it increases capacity

for observation of the object one desires to know about, and it largely determines what one desires to see. The skill of experts in any sort of observation depends upon training. The skill of expert microscopists in any realm, of musical critics, of tea and wine tasters, and of the woodsman in tracking game and in seeing the signs of the forest, all comes from training. The expertness depends in part upon knowing what to look for, of having in mind the problems that are to be solved in a particular connection; in part, the skill in discrimination grows with practice, and is probably dependent upon a number of physiological factors. Training has also obvious effects in determining what sort of stimuli shall be selected for attention. This works in two ways. In the first place, it helps to raise questions, to organize purposes. One cannot have a purpose without some preliminary knowledge of the thing to be seen. What to look for in animal structures is known in any considerable degree only by individuals with some training in zoölogy. The trained machinist has at once a series of questions in mind as he begins to examine the engine that you have called him to repair, and with these problems that have grown out of his experience he looks with a definite series of purposes and easily discovers the source of trouble. But, secondly, even with no definitely conscious purpose, one sees the things that one has been accustomed to deal with, or that one has been trained to see. The printer unintentionally sees details of a book that escape the ordinary reader.

Social Forces in Attention. — Still another group of influences that play an important part are the outgrowth

of social training. These are found in the ideals that one takes from society, the feeling that one must strive to see certain things because of the fact that others expect it to be done. One attends to a lesson when fatigued or when the lesson is not interesting in itself because one desires to make a good record, to pass an examination. One desires to make a good record again for the sake of the approval it will win from persons one respects. Or in a more permanent effect, one desires to obtain a satisfactory knowledge of the subject for the value it may have in later years, or in the profession that has been adopted. Again, however, choice of a profession depends largely upon the social favor that the profession has in the group with which one is acquainted. Even the belief that the particular subject will help in the profession is often taken from society. It is a preference for the remote as opposed to the immediate good, but the more remote is accepted as good and obtains impelling force because of the influence of society. Society approves each separate step, as well as the attainment of the end, its pressure is felt throughout the whole course of the attainment, and thus at once guides and compels towards that end. For our present purpose it may be regarded as the source of all attention from constraint, of all attention against one's momentary desire.

Heredity and Attention. — A final condition of attention, most remote in time, is found in the hereditary disposition. This heredity may be either immediate, as in the inheritance of individual traits, or remote, as in attention due to general instinct. The former is less easy to illustrate or to demonstrate, but it seems probable from

special studies in attention and more general studies in heredity that certain of the tastes of an individual, which are either derived from the natural direction of his attention or control it in certain respects, are inherited from his parents. Galton showed that marked ability and interest in science and in different professions tend to run in families, and his results have been confirmed by numerous studies. The more general heredity is seen in the fact that one attends to moving objects, to personal combats, to all objects that are likely to be especially beneficial or injurious. In general, if one asks why one attends to anything at a particular time, the answer may be found in the nature of the external objects, or in the different mental states at the moment, in the experience of the immediate or of the remote past, and finally in the inheritance of the individual. As has been pointed out, these coöperate in many ways and vary independently from moment to moment, but could we know the individual completely in all of his characteristics, his past history, and the influences working upon him from the environment, it would be possible to say fairly closely, even with our present knowledge, what he would be likely to attend to.

Control of Association. — Selection is quite as important in controlling the course of the associations or in determining the ideas that shall be recalled or suggested, as in selecting the sensations that enter consciousness. It is evident that the mere strength of connection between ideas would give only a rigid, mechanically determined series of thoughts with no flexibility and with no possibility of logical connections nor any purposiveness in

the thinking. This inadequacy of the associative connections to explain the real course of thinking has led many to abandon the theory altogether, in spite of the fact that in some degree the importance of old relations in determining what shall be recalled has been recognized all through the history of psychology. It seems more in harmony with the facts to accept the view that fundamentally all recall goes back to association, that each impression recalled must be suggested by the preceding, but that since each idea has been connected with many others, there must be other conditions that have united to bring back just that idea and no other; or, speaking in advance of the return of the second, that which shall be aroused of the many ideas that have been connected with the first depends upon a number of other forces, and these work together with the associative tendency in determining the recall.

The Goal Idea. — Two different theories, at present current, attempt to remedy this deficiency in the doctrine of association. One suggested by Aschaffenburg and much used by the psychiatrists would refer the decision of the course of ideas to the effect of the final idea in the series, what they call the goal idea. Thus if the goal of the sentence is to describe the weather, one set of words will be suggested, if to decline an invitation, another series of words may be called out, even if one start with the same word. When the course of thought leads to the goal, it is said that the goal idea dominated it; if it wanders at random by virtue of the strength of the connections between each pair of ideas, we have to do with another sort of thought. For the

diagnosis of mental disease, thinking dominated by goal ideas is normal, while, when the goal idea is lacking or is of slight effect, one has an indication of mental abnormality. There can be no doubt that these terms describe an important difference between types of thought, that associations may be classified along these lines. The objection is that it gives merely a descriptive classification rather than an indication of the effective causes or conditions. One cannot think of the last idea in the series as exerting an influence upon those that precede it. A force cannot be regarded as exerting an influence before it comes into being.

Association Controlled by Conditions of Attention. — On the other theory the same facts are taken into consideration, but the explanation is in terms of determinants rather than of goals, of antecedent rather than of consequent events. We may take over almost bodily our conditions of attention and apply them to enumerate the factors that determine the selection of one possible associate from the others. What correspond to the objective conditions here are the factors that determine the strength of the connection between one element and those that have been associated with it. These have been shown to be the frequency with which the two elements have appeared together, the recency of their association, the degree in which they were attended to or the strength of the stimuli that called out a response at the time of their earlier appearance, and the primacy of the association. Professor Calkins has shown that the first time an element enters into an association with another, it is more likely to be recalled with that than with any other with

which it has been associated at a later period. It should be added that Galton found that very many of the ideas in a train came from youth. He kept a list of ideas that occurred to him in a period, and then traced them to the time of their original experience. Thirty-nine per cent were found to come from boyhood and youth, forty-six per cent from the period of subsequent manhood, and fifteen per cent from quite recent events. This indicates that impressions received in youth are better retained and are stronger in their connections than those received at later times. This may be said to be due, either to primacy, to the greater degree of retentiveness of the associations first formed, or to the greater interest in the events of the early period of life. Professor Calkins also found that primacy was an important factor in the determination of the strength of associates, even when they were formed in adult life. A number of experiments from Ebbinghaus prove that both the frequency and recency of associations are important elements in the determination of the probability of recall. Intensity does not lend itself so well to experimentation, but chance observation indicates that the more intense stimulations leave more permanent effects. Under this head come cases in which the intensity is of subjective origin, is due to a strong feeling or to close attention. It has been shown that the degree of attention increases the likelihood of recall, and, while the experimental case for feeling is not so complete, there is good evidence from everyday life that this, too, serves to increase the closeness of the connection. As a result of these objective conditions, the tendency of any idea or partially aroused

neurone to arouse some other is constant. Furthermore, were this strength of connection the only thing to be taken into consideration, it would be very difficult for the connections to be changed. The idea recalled by any given idea would be determined once and for all. The only way one association could be broken and another substituted would be to permit a long lapse of time and the formation of some very strong new association. It would mean, in any mind subject to its rule, a perfect mechanism with no possibility of breaking away from its domination.

Subjective Conditions of Recall. — This tyranny of association is tempered by the subjective conditions of attention which play a part here, as well as in the entrance of sensations to consciousness. By far the most important of these is to be found in the mental attitude of the moment, the purpose or problem that is set the individual. If one be given such a word as *dog*, it is possible for a very large number of associates to be recalled. If, however, it is coupled with the request to name the class to which it belongs, vertebrate, animal, or some other more general term will come. While if one is asked to give a member of the class, a species of dog or the name of some particular dog is spoken. There is still room for selection within the group, but the group itself is very much narrowed. Similarly, if two numbers are shown written one above the other and a line drawn beneath, as $\frac{12}{6}$, 6, 18, or 72 might be associated with them. If they appear in a check book or in other real relations, the purpose and the

knowledge of what has gone before serve to determine whether one or another shall suggest itself. If the problem is set by another, if the sum appears in a series in which one has been asked to add, subtract, or multiply, that request will suffice to suggest the corresponding figure. In any case, either the task that has been set by another, the demands of the situation, or the attitude that one may happen to be in will choose from among the possible associates the one most suitable. In addition to the setting, education and the social influences that are behind voluntary control of attention also have an important part in the guidance of ideas. While association provides the possible paths along which ideas may flow, these possibilities are made actualities by the more subjective conditions derived from the earlier experience and present intentions of the individual, and the necessities that bear upon him at the moment. All the factors that control attention serve also to select the associates.

Forms of Attention. — It is customary to divide attention, whether applied to external objects or to the control of ideas, into three groups, — voluntary, involuntary, and non-voluntary. In popular terms the basis of division is with reference to the presence or absence of the will. As we do not care to raise the question of the will at the present time, we can make the classification with reference to the conditions and characteristics of the attention process discussed above. In general, it can be seen that the attention called involuntary corresponds to attention that is determined altogether by the objective factors. We attend in spite of ourselves

because the stimulus is strong enough to force itself into consciousness, whatever the state of consciousness itself may be at the moment. Attending is against the will, against the desire of the individual at the moment. We desire to read, and the noises of the street force themselves upon us, or we desire to recall the book in which a certain statement was made, and a large number of ideas keep forcing themselves upon us. In the latter case the associations of irrelevant things are so strong that the relevant idea is kept out.

Voluntary attention, on the other hand, is that which is determined by social pressure. The desire to attend is not one that springs spontaneously, but is due to the impulsion of some remote end. In most cases a struggle between the immediate and the remote good or pleasure is involved. Usually, too, as has been said, the remote good is impressed upon us by some form of social pressure. The approval of some part of the immediate social group is necessary to make the distant goal more attractive than the inherently pleasant processes that would lead us away from it. In this sense social pressure is the real motive force behind attention, the force that holds the individual to the less pleasant in the face of the more pleasant. The characteristic conscious accompaniment of voluntary attention is a mass of strain sensations, sensations which, taken together, constitute the feeling of effort. As was said in the discussion of the motor accompaniments of attention, all attention involving conflict of motives tends to arouse diffuse contractions in a number of muscles, contractions which are in themselves of no great effect upon the attention process, but

which are accepted as an indication that some force is active. They make us feel active, are said to constitute a sign of the activity of the will. So far as we now know, they are not a cause but an effect, they are a sign, not of a new force, but of a conflict of conditions. That they have no good effect is evident from the fact that they do not accompany the most effective attention and, when they appear, usually die away as soon as the highest stage of efficiency of attention is attained. Voluntary attention is due to social pressure and is accompanied by strain sensations. All strain sensations taken together constitute what we call the feeling of effort.

The non-voluntary form of attention includes all classes not previously covered. The more important conditions are the mental attitude of the moment, the momentary purpose, education, and heredity or instinct. These seem to induce attention in accordance with the momentary nature of the individual; they constitute in sum total the conditions of desire. The characteristic accompaniment of this form of attention is interest, a feeling of pleasure due to the lack of conflict. In so far as it is strictly interest, it is a pleasure derived from the mere act of attending, rather than from the nature of the thing attended to. Why it should come or how it originates need not concern us here; in fact, no satisfactory explanation has been given for it. It is essential to emphasize that both it and the feeling of effort are accompaniments or effects, not causes, — are signs of the lack of conflict between motives on the one hand, and of conflict on the other. After all, then, these three divisions of attention are not entirely distinct. They produce the same effect

in consciousness; they are distinct only in the sensations of effort and the feeling of interest which accompany them and in their conditions, and these shade gradually over into each other without sharp line of division. Attention is a unitary process.

The Physiological Explanation of Attention. — On its physiological or nervous side, attention may best be pictured as a preparation of one tract or set of tracts for action. The nature of this preparation in advance of the entrance of an idea varies for the different subjective conditions. The immediately preceding stimulus and the idea in mind can be pictured as due to the effect of a previous stimulation of the same tracts, which in consequence are still partially active at the moment the new excitation is received. This corresponds to the fact noted in the preceding chapter that the nervous response continues for several seconds in relatively high degree and probably for a considerably longer time in some degree. The entering stimulus, finding these tracts already active, produces a greater excitation than it otherwise would or, if several stimuli of approximately equal intensity are presenting themselves, that one produces its effect for which the way has been prepared by this partial excitation. The influence of attitude or purpose is the result of the spreading to a large number of associated paths of the impulse developed by the stimulus that arouses the attitude. Many of the neurones connected with the first are partially aroused by it, and the entering stimulus needs only to complete the excitation already begun to become conscious. The effect of education is to prepare these systems of paths so that they

may be excited by the particular stimuli or the particular occasions. It is essentially a process of organizing cerebral cells into groups so that one entire group, as well as some particular associate, may be aroused or partially aroused by a suitable stimulus. In addition to this process of partially exciting the areas that are to respond, it is necessary to assume that other groups of neurones are active in facilitating or inhibiting the activity of the tracts immediately concerned. An activity of one group makes easier the arousing of certain others related to it, and may at the same time make more difficult the arousal of other groups. An idea may be said to facilitate certain ideas and to inhibit others. Each of these processes may be regarded as an explanation of the selection, either from among the stimuli which seek to enter consciousness, or between ideas that are associated with the particular idea that serves as excitant. Thus on the nervous side, the course of impulses is determined by the action of very large numbers of neurones, many of them very remote from the neurones which are actually the seat of the processes attended to. The cortex acts as a unit rather than in parts, just as, on the side of consciousness, practically all experience unites in determining the course of any single element of consciousness.

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CHAPTER VIII

PERCEPTION — SPACE

So far we have been dealing with the preliminaries of psychology, with the physiological substrate, and the fundamental laws and the elementary structures of mind. We must now turn to a study of the actual mental content. In practice we think not at all of sensations or of laws of association; on the contrary, we think always of things and of events. We are anxious to know, not what the sensational basis of our observations may be, but the nature of the object seen, what it is in itself independent of our seeing. We deal immediately with objects and only occasionally are we interested to know what the mental state that represents the object may be. We must now begin to study these objects and how we become aware of them or derive them from the immediate sensations. We may think of our knowledge of objects as dependent upon sensations. Certain schools of psychologists assert that they are complexes of sensations, that things are compounded of sensation as water is compounded of oxygen and hydrogen. A little observation shows that objects are not merely sensations. We seldom see all that we ascribe to the object and, on the contrary, we do not ascribe to the object all that we see. From our present point of view,

we must accept the common-sense standpoint that the object is the reality, and that the sensation is an abstraction which the psychologist has developed in an endeavor to understand the actual experiences. The same statement may be made of thoughts and even memories. When we remember we do not reinstate the event or even the perception of the event, we only refer to it. Even more truly in thought we have assurance that things are of a certain form but we do not reinstate them. We think of the objects and their relations alone.

It is evident, then, that we must distinguish between the object and the mental content that we have been considering heretofore. The psychologist naturally inclines to the view that what he has discovered to be the immediate content — the sensations and the centrally excited sensations — are the realities of mind, while the common-sense man insists that he has objects in mind and objects alone. While this question borders upon one of the fields most hotly contested among philosophers to-day, and while we need attempt to give no final decision, it is possible to state a position which will sufficiently reconcile conflicting opinions to give us a satisfactory basis for our further discussions. First we must admit that the naïve mind and all minds in naïve moments deal directly with objects. Secondly these objects are not merely compounds of mental elements. But, on the other hand, we can obtain a knowledge of these objects only through the senses, and in many cases they can be recalled or reinstated only by means of centrally excited sensations. Two attitudes may be taken towards the fact. One would assert that

by some process of completion or perfection the sensations and other mental elements may be developed into objects or more perfect counterparts of objects than are the bare sensations; the other, that the object is only meant or represented. The mental state is not the object as we think it, it need not be like that object, but yet does duty for it in all mental operations. We may grant for the present that there is something of both of these processes. What we see is corrected and developed in certain respects to constitute a real mental state which replaces the bare sensations. At the same time all that is intended is never given in the mental states. The mental content merely means what we are thinking about; it does not reproduce it or constitute it.

In much of the discussion to follow we shall be concerned with tracing the factors that aid in the transformation of the sensations into objects. We shall endeavor to discover what it is that determines the transformation, and also keep constantly in mind the problem of the way in which elementary mental states come to mean that which they are not. We can expect to form a decision as to the nature of the meaning and the difference between the mere mental state and the thing it represents only after an empirical study of the many different facts.

Temporally first and in many ways simplest of the concrete mental processes is perception, the appreciation of things as real objects. An object may be considered and has been considered as a group of sensations entering consciousness together. If one were to accept the theory

that a percept is a compound of sensations, the perception of a bell might be said to be composed of a group of visual sensations, colors of certain shapes, tones of a given quality, sensations of pressure and temperature, all grouped in a definite position at a definite distance. Closely examined, however, this description is soon seen to be inadequate. In the first place percepts involve more than sensations. Frequently, in fact usually, one adds to the actually given sensations memory qualities that are not present at the time. As one hears the bell, its picture is recalled; the sound alone cannot be said to constitute the percept. Again, more is involved in the percept than can be given by the sensations alone even if we include both immediate and reinstated. Aristotle found it necessary to provide a 'common sense' that should remove the discrepancies between the different senses, which he found to be constantly in evidence. We shall see that this correction of the experience, the harmonization of elements, plays an important part in all perceptions.

Tonal Fusion.— The only perception that approximates the bare combination of sensations into a larger or more complicated whole is the tonal fusion, the combination of simple notes into chords or of fundamental and overtones to constitute the timbre of a musical instrument. As was seen in the discussion of tones, the chords have a quality which varies with the ratios of the vibration rates of the notes that combine to produce them. This quality evidently depends upon the simultaneous stimulation of the sense organ or cortex by these tones, but why their composition should give rise to the

effects that are produced is not at all agreed upon. Helmholtz suggested that it might be due to beats between the fundamentals or between overtones or fundamentals and overtones, but Stumpf found several cases in which the relative degree of fusion did not follow the order of complexity of beats. Stumpf then goes to the other extreme, insisting that the primary fact is fusion, that this is closely related to harmony, and cannot be explained in any way other than by ultimate connections in the nervous system. Certain pairs of tones arouse more nearly the same processes in consciousness, have what he calls a 'specific synergy,' which makes it very difficult to distinguish them. It seems that in general this relation becomes less and less close as numerator and denominator of the fractions designating the interval relation become larger, as, *e.g.*, one passes from the $\frac{2}{3}$ of the fifth to the $\frac{8}{9}$ of the major second, or the $\frac{8}{15}$ of the major seventh. No attempt is made to explain why the 'specific synergy' should exist between one pair of tones and not between others. Other authorities assume an almost mystical connection between the tones in question and a hypothetical common ground tone to which each might be related as an overtone. Some appreciation of this relationship is supposed to determine the harmony, or its lack. Obviously there is no simple answer to the question why certain tones fuse.

Even if tonal fusion is mere fusion so far as consonance is concerned, there are always involved in the total appreciation of a tone group many elements derived from earlier experience. That the most pleasing combination

varies with the training of the individual, is different for the occidental and oriental, and for the occidental music at different stages in its development, is fair evidence that we are not dealing here with a mere combination of elements. In connection with the same interval on different instruments, one may distinguish old memories that serve to change its character as well as its reference. In distinguishing and remembering intervals, the name of the complex plays a considerable part. Some interpretation is added to the mere complex of sensations. Even in this apparently simplest case of combination of simple sensations to make a total percept, there are additions from memory, and there are interpretations derived perhaps from very complex experiences which play a part in determining what the particular experience shall be.

When we pass to percepts in which reference to things is more explicit, as it is in practically all perception, the complexity of the processes involved in the construction is even more marked. In the study of perception of objects in general, we find it advantageous to consider first the more general characteristics of all experience and leave to the last the illustrations of general laws derived from the particular perceptions. All experiences occur in time, and we are accustomed to abstract the temporal characteristic from the different experiences and to regard it as if it were independent. While this abstract time undergoes many variations according to the particular experiences that occur in it, it is convenient to consider this phase of experience apart from the others, and to regard the changes due to the nature of the filling

as exceptions to the general rule. Space also is involved in the perception of all objects and is directly appreciated by four of the senses. Other general aspects of experience are motion and rhythm. Each of these can be treated apart from its particular content and this simplifies the treatment of the perception of particular objects. We may begin with the discussion of space.

The Perception of Space

Space is appreciated by means of at least four senses, — touch, vision, hearing, and the kinæsthetic sense. Of these, vision gives the most accurate and complete appreciation, touch combined with the kinæsthetic impressions stands next in definiteness, and the auditory space last. In actual practice all objects that are recognized as objects are given a position in space, whether they are actually sensed or merely recalled. In the other senses, the spatial aspects are ascribed to one of the more definitely spatial senses — tastes to the tactual impressions also received from the tongue, *e.g.*, — or are somewhat indefinitely referred to space in general. Odors are usually ascribed to objects, but the localization is always uncertain and the quality may be thought of as independent of the organ, as general or all pervasive. Not only are the subordinate sensations referred to sight, but there is much cross reference between the higher senses. Different senses predominate in different individuals, but in all space interpretations more than one sense are involved.

Three different complexities of the space problem present themselves, although for sight and kinæsthetic im-

pressions alone are all to be considered. These are the appreciation of position, of extent in two dimensions, and of distance or depth, the third dimension. The skin appreciates position and extent alone; the ear, distance and direction alone. We can start with the simplest problem in each sense and transfer what may be gained from that to the more complicated constructions.

Perception of Tactual Space. — Theoretically simplest of the space problems is the appreciation of the position of a point upon the skin. Experiments have frequently been made to determine how accurately a spot upon the skin may be localized. If one attempt to touch a spot on the skin, one will note an error that averages a centimetre or so on the wrist or on the back of the hand, is smaller on the fingers, and considerably larger on the portions of the body ordinarily covered. This simple experiment indicates two facts: one, that there must be something that guides the movement, some immediate awareness of where the point touched is; and secondly, that this localization is not absolute, that it is subject to error and more or less variable. One of the first theoretical attempts to determine what it is that gives a knowledge of position was made by Lotze. Lotze pictured the self as somewhere in the brain and as receiving impressions over the nerves from the surface of the body. Such a self might be pictured as constantly questioning what part of the skin gives rise to the sensations it received and seeking for signs that indicate their origin. Lotze asserted that the sensations received from different parts of the skin had different qualities. These different qualities were not described

very definitely, but apparently were due in part to the character of the skin and the amount of tissue that lay between it and the bone. The quality of any spot on the skin he called its ' local sign.' If you will try to discover this local sign in the sensations from your own skin, you will find it very difficult. Careful examination of the sensations fails to disclose any such quality in addition to the ordinary skin sensations, — one knows immediately where the touch is but does not know how he knows, — an almost universal condition in perception.

Indirect methods of analyzing the local sign or means of localization indicate that it is dependent in part upon the nerve stimulated. When a member has been amputated, the sensations from the stump are still referred to the missing part, and when a portion of the skin has been displaced by a surgical operation without severing the nerves that supply it, sensations from the skin will for a time be given the old position. It is true, too, that the accuracy of localization is greatest where the nerve endings are most numerous. These factors might be explained on Lotze's assumption that each nerve had a ' local sign.' They also have been interpreted to mean that localization is due to the movements called out reflexly. If each point on the skin were connected with a set of motor neurones that would cause the hand to move to the point touched or that would call out a slight movement toward the point, the movement might be used as a sign of the position. This motor theory receives some support from the fact that animals, whose brains have been removed, and men in their sleep, will touch the

point stimulated with a fair degree of accuracy. That it alone is not sufficient is probable from the fact that the normal animal makes the movement with greater accuracy. Still a third theory would make the localization due to the association of other sensations with cutaneous excitation. Often a picture of the point touched comes immediately upon contact. However, no one of these theories may be regarded as sufficient in itself. Rather must we assume that all have acted together to give a notion of each different position on the skin. As different points have been touched, the kinæsthetic have been associated with the visual sensations, and these with the sensations of contact and with any other impressions that may be concerned. After the notion has been developed it is called up by any contact.

The ' Limen of Two-ness.' — Much the same problem meets us in connection with the appreciation of a minimal extent. This has been studied by determining the least distance at which two points might be appreciated as two. Weber, who made the first experiments, found that this distance varied from approximately 1 mm. on the finger tips and tip of the tongue to 40–60 mm. on the middle of the back. In general it was larger on the portions of the body ordinarily covered and, on the limbs, decreased regularly from the centre of rotation downward. Volkmann noted that it varies approximately with the amount of motion of the member and of the parts of the member in question. Goldscheider repeated the experiments by putting the points of a compass upon pressure spots, and found that two points might be dis-

tinguished when the points were on contiguous spots. His values varied from 0.3–0.6 mm. on tongue and finger tip to 4–6 mm. on the back. Later experiments by von Frey indicated that these values were too small unless the stimuli were applied successively. In these experiments, as in comparisons in general, successive stimuli are judged more accurately than simultaneous stimuli. It is also to be noted that practice and suggestion have marked effects. Values may be reduced one-half or more in a few weeks' practice. It is seen, too, that practice on one part of the body will have an effect upon the symmetrical areas that have not themselves been exercised.

The explanation of these values may be reduced in part to a matter of comparing 'local signs.' When two signs of position are much alike, they are confused and made to constitute one point. By sign of position may be meant, either actual sensory quality if that exist, or two movements or the suggested motion from one to the other, or reference to visual distances. Improvement with practice is suggestive of this process of analysis as is also the greater acuity on the more mobile and in consequence more used members. Larger extents probably depend more upon movement from one point to the other, either of the member itself or of another exploring organ. A curious illusion that arises in the comparison of filled with empty space would indicate that the nature of the stimulation plays a part. If one is asked to compare a single empty space with a space containing other stimulated points, the empty space seems greater than the interrupted space. The explanation is difficult in

terms either of movement or analysis. The importance of reference to vision should also be emphasized. Many individuals translate cutaneous sensations into vision and do not appreciate the distance until this translation is complete. This statement may be verified if one will have another trace outlines on the skin, or press objects of different shapes against it. The blind must of course have an immediate appreciation in terms of pure cutaneous impressions or of movements. How these different factors coöperate is not as yet known, but it is undoubtedly a process that is much more complicated than the simple theories we have indicated would make possible.

Retinal Local Sign. — If one may explain something of the spatial perception on the skin by reference to the influence of vision, it is also necessary to understand how position and extent may be perceived on the retina. The same problems meet us here and many of the same facts are present to provide the data for discussion. There is a lower limit of distance that must separate two points if they are to be perceived as two. On the fovea if two dots or lines are nearer together than .004–.006 mm., or an angular distance of 60″–90″, they fuse into a single line or dot. This may be regarded as the ' limen of two-ness ' for sight. The effects of the inability to distinguish lines and points closer together than this minimum can be seen in the ability to distinguish letters in reading. The normal eye can read letters when the width of the separate lines and the distances that separate them are each 1′. The Snellen types in the adjoining figure can be read at a distance such that the

lines are separated by this amount or by .004 mm. on the retina. Stratton found that if two vertical lines placed one above the other were brought together at their extremities, a break in the line could be noted when they were displaced 7″ only. In this case, however, the difference in direction of the lines probably also plays a part; it is not merely appreciation of the distance between points. As the distance that separates the centres of cones in the fovea is only about 40″–60″, it would seem that stimuli no farther apart than the centres of neighboring cones can be discriminated. As one proceeds outward from the fovea, the acuity diminishes very rapidly. Five degrees from the centre it has been reduced to one-fourth and at forty degrees to one two-hundredth of the maximum value. In twilight vision, where the cones are not involved, acuity is approximately the same in all portions of the field beyond ten degrees from the centre. It is zero in the fovea itself and rises very rapidly until the stimuli affect the retina five to ten degrees distant from it.

Fig. 67. — Snellen types.

The theories of the appreciation of position and extent upon the retina involve the same principles as those advanced for the skin. The awareness of position seems to depend in some way upon the nerve element stimulated, as is evidenced by the fact that when a retinal element is displaced it still gives the old sign of position. Thus Wundt at one time suffered from choroiditis under one small portion of the retina. This caused a swelling of the retina and finally resulted in a small scotoma or

blind spot. While the elements of the retina were displaced in this region, the straight lines seen on it were distorted, and it was only after the rods and cones had been used in their new positions for a considerable time that the spatial relations became normal again. This sign of position that attaches to the retinal element has been ascribed to the conjectural 'local sign' and to movement. Differences in the qualities of sensations received on different areas of the retina have been suggested as furnishing the means of distinguishing position. Even the difference in the quality of a color has been suggested as a sign. In the movement theory it is assumed that the tendency of the eye to turn in such a way that the point attended to shall fall upon the fovea constitutes the mark of position. The more general and inclusive the final explanation, the greater the likelihood that it will be correct. It is probable that the idea of position here, too, is a notion that has been gradually developed through experience of all possible sorts, that it includes reference to motion, to areas as known on the skin, and particularly to the movement of the fingers over surfaces as eye and finger explore them together, and a large number of more general practical tests. After the complex has developed, some peculiarity in the retinal element stimulated or the activities aroused by the stimulation suggest this idea or concept. Either such a highly complex concept of position whose origin has been lost in the course of its development, and which is now appreciated only for its meaning, must be assumed to constitute our idea of position, or one must leave the problem unsolved.

The perception of greater visual extents depends very largely upon the eye movements. It has been investigated with more care for the eye than for the skin. Studies in the comparison of two lines show that the appreciation of distance follows Weber's law, — one can appreciate an addition in length of from $\frac{1}{40}$ to $\frac{1}{60}$ to a horizontal line, an average of about $\frac{1}{50}$. Appreciation of difference in the length of vertical lines is slightly less accurate, an average of about $\frac{1}{40}$. This slighter degree of accuracy in perception of vertical movements has been connected with the fact that the vertical movements require two pairs of muscles and so a greater amount of effort than horizontal movements. They are thus less accurate and more difficult to compare. As one estimates the length of a line, the eyes move from one end to the other and the comparison is probably very largely in terms of these movements. The qualitative characteristics or group of ' local signs ' may also play a part but here, as in the liminal values, they have not been clearly discriminated.

The Eye Muscles. — The importance of eye movement in the perception of space makes it desirable to give a brief statement of the muscular mechanism. The eye is moved by six muscles arranged in pairs and named, from functions and attachments, the internal and external recti, the inferior and superior recti, and the inferior and superior oblique. The recti muscles all spring from near the apex of the eye socket and pass directly forward to their point of attachment on the surface of the eyeball. The superior oblique also originates at the apex but runs forward to a ring of cartilage

on the upper nasal rim of the socket and then turns backward to be attached behind the centre of the upper surface of the eyeball. The inferior oblique springs from the lower nasal rim of the socket and passes back to a point behind the middle of the lower surface. From the fact that the oblique muscles exert their pull toward the front, they turn the eyes in the direction opposed

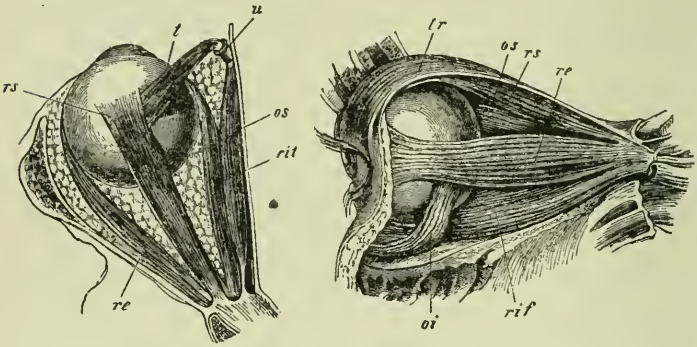

FIG. 68. — Muscles of the eye. *rs*, superior rectus; *rif*, rectus inferior; *re*, external rectus; *rit*, rectus internus; *os*, superior oblique; *oi*, inferior oblique; *t*, tendon of superior oblique which runs through the membranous pulley, *u*, on nasal wall of the socket.

to their names. The direction in which the muscles turn the eyeball may be best indicated by the diagram taken from Hering. It will be seen that the internal and external recti muscles turn the eye in an approximately straight line; all the others turn it along a curve and if the eye is to be moved directly up or directly down, two muscles must coöperate (Fig. 69).

The eyeball turns about a point about 1.3 mm. behind the centre of the eye. The centre of rotation is 13.5 mm. back of the cornea. It should not be assumed that

this point is absolutely fixed, — owing to the loose way in which the eyeball is held in its socket, it is slightly displaced as it turns, and the centre of rotation moves with it. Also as the eyeball turns, it is rotated more or less about its optic axis. This is called torsion. The amount of torsion increases with the amount of the movement, but is always present even for slight movements. Both eyes always move together. A single impulse is sent simultaneously to the same muscles of both eyes. It is as if they were a team of horses turned by a single pull on a pair of reins. These movements follow the direction of attention, as was said in an earlier chapter. The only conscious antecedent is that some object in the field of vision shall catch the attention, then the eye muscles immediately contract in a way to bring both eyes to fixate the object. As points of reference for eye movements, one may distinguish certain positions. What is known as the primary position is that which the eyes have when fixed on a distant object in the median plane and a little (15°) below the horizontal. From this, movements may be made in any direction with the optic axes parallel, or the eyes may be converged upon points in the median plane or to one side of it. These positions have been called secondary and tertiary, but no agreement as to which are to be called secondary and which tertiary has been attained.

The fact that we always use two eyes instead of one offers several problems of interest as to how two impressions can combine in one, what part each contributes, and the advantages of binocular as compared with monocular vision. In general, it may be said that for most

purposes the two eyes act almost as one organ. If a plane surface be presented to both eyes, we see it single and not appreciably different from the same surface as seen by a single retina. When different objects are presented to the surfaces of the two retinas, the result

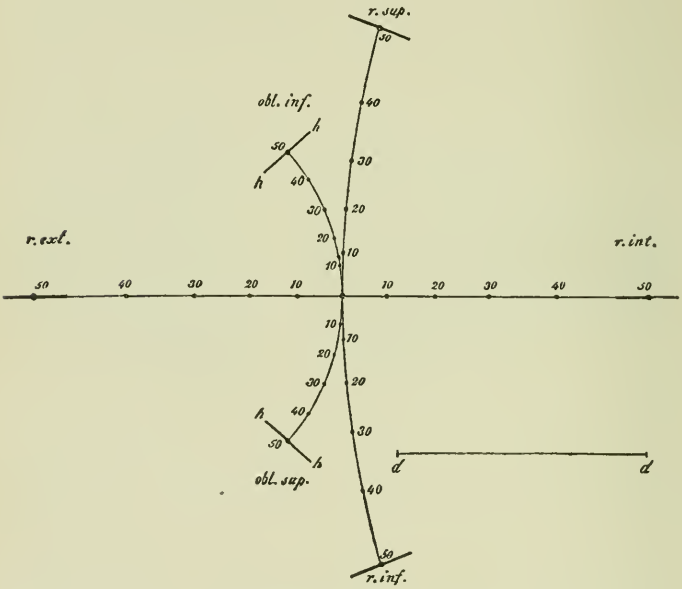

FIG. 69. — Hering's diagram of eye-movements, showing course the eye would follow if pulled by each muscle singly.

may be that (1) the two may fuse to produce a new quality, (2) one may suppress the other entirely, or (3) first one may be seen, then the other. Colors which fuse when they fall upon the same surface in a single eye are likely to fuse when one stimulates one retina, the other the other. For certain individuals there may be

an alternation. Thus, if one half of a stereoscopic slide be red and the other blue, when looked at in the stereoscope they will ordinarily give a purple, but at times and in part of the field an individual will see first the red and then the blue. Where a contour of any kind is presented to one eye and a plane surface to the other, as in Figure 70, the contours will be noticed and the plane surface neglected. The law may be formulated in the statement that you see what means most to you, what is most interesting, while you neglect the unimportant plane surface. Where two colors or grays, alike except in brightness, are combined, the result is a single color with a brightness intermediate between that of the components. The brightness is usually a little greater than the average for the two stimuli. Thus, when the two are of the same brightness, the brightness of the combined image may be $\frac{1}{10}$ greater than that of either alone, and when they are very different, the brighter may have its brightness reduced by the darker. This latter is known as Fechner's paradox, since the addition of the fainter brightness to the greater reduces rather than increases the brighter. A contrast color may also be induced in one eye by stimulation of the other.

FIG. 70.—Stereoscope slide that shows the effect of contours. (From Titchener, "Experimental Psychology.")

Corresponding Points. — Very important for the space problems is an understanding of the arrangement of the points or lines that are seen singly. If vertical lines, one on one half, the other on the other of the stereoscope slide be seen in the stereoscope, it will be found that the

lines will be seen as one if they are so placed that the images fall on corresponding points, *i.e.*, on points that are the same distance from the fovea and in the same direction. If both are vertical and pass through the fovea, they will be seen as one; if one pass through the fovea, the other through a point one degree to either side of it, both will be seen. Corresponding points may be defined as those equidistant from the fovea and in the same direction from it. If the two retinas could be placed one over the other in such a way that the foveas and the vertical and horizontal axes coincided, then all points that were superimposed would be corresponding points. Stated in terms of rays of light, those rays fall upon corresponding points which make the same angle with the lines of sight of each eye and in the same direction. The line of sight is the line from the fixation point to the fovea. The most important problem for the perception of space is to determine how much two stimuli must depart from correspondence before they can be seen as two or, in terms of our first problem, how far the two lines on the stereoscopic slide may depart from correspondence before they will seem to be two. Pulfrich[1] and Bourdon[2] found that two objects need have no greater deviation from correspondence than from 5″ to 12″ for the deviation to be noticed. This is about the same as, or even less than, the 'limen of two-ness' for a single eye. It should be added that the lines are not necessarily seen as two, but the divergence may be translated into depth, as

[1] Physikal. Zeitschrift, 1899, No. 9.
[2] Revue Philosophique, vol. 25, p. 74.

will be seen in a later discussion. Considerably greater deviations from correspondence may take place without being noticed if the lines are horizontal than if vertical.

Why two points should thus give rise to but a single image is not easy to say. The first theory, suggested by Johannes Müller, was that it was due to the fact that corresponding points were connected with the same half of the brain. It is a fact that the right half of each retina is connected with the right hemisphere, and each left half with the left hemisphere. There is, as the diagram (p. 59) shows, only a partial crossing at the chiasma, — half of the fibres cross and half go uncrossed to the same side of the brain. Müller assumed that these fibres in some way combine in the cortex, perhaps connect with the same cells, and so give rise to a single image. This would be the nativistic explanation; the combination would be due to the innate nervous connections. The empiricist, however, can cite numerous cases in which this correspondence is changed by experience. Individuals whose eyes are badly crossed, who squint, develop a new set of corresponding points; the points that have been used in seeing the same object come to give single images, or else the image from one eye is disregarded. Similarly, horizontal lines may be a considerably greater distance apart than vertical ones and still correspond. Under those circumstances it is more likely that there is one line than two. If the lines be vertical and deviate very slightly from correspondence, they will be seen as two. We shall see that this deviation from correspondence of vertical lines is an important factor in the appreciation of distance

and so is noticed, while the necessity for distinguishing horizontal lines is relatively slight. The empiricist's explanation would be that we see the two images as one because tests by touch or other senses have shown that there is only one object present in spite of the two images; we have learned that two images mean one object, and the positions that are most frequently stimulated together by a single object become corresponding points.

The Horopter. — The problems of binocular vision and corresponding points are of interest because of the light that they throw upon the positions that objects in space must occupy if they are to be seen singly. When the eyes are converged in a given position, there is only one distance from which rays of light can fall upon corresponding points. The distance varies as convergence varies, but the locus of points in space which will send rays to corresponding points is strictly limited. Points nearer or more remote will fall upon non-corresponding points and so give double images. The locus of all points that fall upon corresponding points is called the horopter. The form of the horopter has been developed mathematically in great detail. Since the assumptions upon which the computations are based do not correspond accurately to the actual facts of vision, we need pay little attention to the intricacies of the results. Two forms of the horopter may be mentioned. When the eyes are converged upon a point in the plane half way between them, the horopter is a circle passing through the fixation point and the nodal points of both eyes. To this is added a vertical line through the fixation point. When the eyes are parallel, all points at an in-

finite distance, the distance at which parallel lines meet, would fall in the horopter, theoretically. In practice, the horopter is composed of all space beyond the point

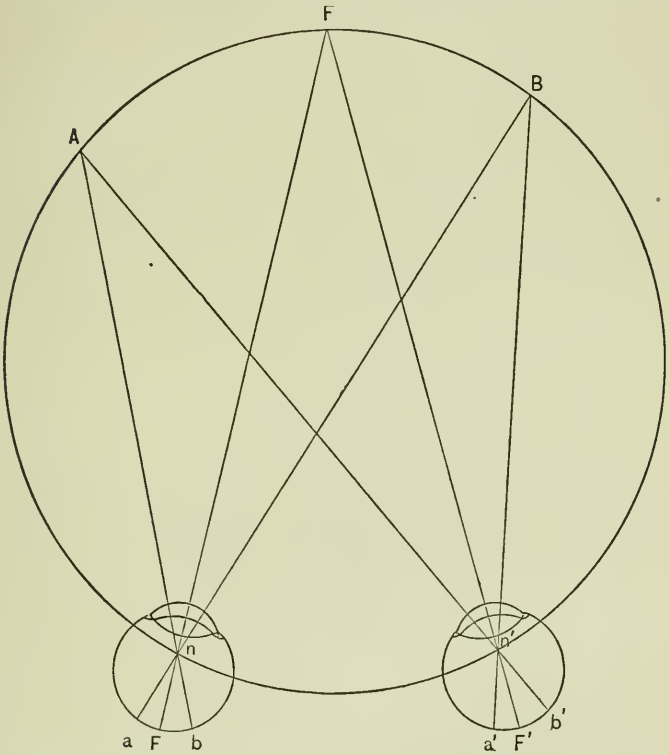

FIG. 71. — Müller's Horopter Circle. *a* and *a'*, *b* and *b'* are corresponding points. Lines drawn from these points through the nodal point will meet in a circle that passes through the fixation point *F* and through the two nodal points, *n* and *n'*.

where the departure from the parallel is less than 5″, the least disparateness that can be appreciated, or some 2500 metres.

U

The Perception of Distance. — We have now to consider the application of the different facts of vision so far collected to the perception of the distance of objects from us, what may be called depth or the third dimension. We may speak first of the elements which are derived from the structure of the eyes and which in consequence are usually spoken of as the primary or physiological factors. With the single eye the most important is the accommodation of the lens for different distances. As was said in an earlier chapter, when a near object is attended to, the ciliary muscle is contracted and this permits the lens to thicken and give a clear image of the object. On the other hand, when a more distant object is attended to, the ciliary muscle is relaxed and the lens is flattened by the tension on the suspensory ligament and so adapted to receive a clear image from distant objects. The degree of strain varies inversely as the distance, and is apparently interpreted to mean the distance of the object. One thinks of objects that are seen with much strain as near, those that are seen without strain as remote (no strain is required for objects more than about 50 feet away). As is usual in all perception, these factors are not observed for themselves; the distance alone comes to consciousness.

Convergence as a Factor in Distance Perception. — When two eyes are used for the appreciation of distance, estimates are much more accurate. If one will look with one eye at a landscape, one will notice that it appears much flatter than usual. Or if one will attempt to put a finger through a ring held sidewise by another it will be found very difficult when one eye is closed although

perfectly easy when both eyes are open. New factors obviously must be added when both eyes are used. Two of these are important. One is muscular, the movements required to converge the eyes upon a single object. Distant objects are viewed with the eyes nearly parallel and with the muscles fairly completely relaxed. As an object comes nearer, it is necessary to contract the internal recti muscles if the eyes are to converge to see it with the foveas. This gives rise to another strain that also decreases with the distance. This strain both is a more accurate index of distance and can be used to detect distance over a longer range than the strain of accommodation. If one compare the distance of a thread seen at different distances first with one eye then with both under conditions that restrict the means of determining distance to the muscular adjustment, it is found that the distances that can be distinguished are much less in the latter case than in the former. This is shown in the accompanying table taken from Wundt.

TABLE I

Uniocular		Binocular Comparison	
Distance	Limen	Limen	Relative Limen
cm.	cm.	cm.	
250	12		
180	8	3.5	1/50
130		2.0	1/64
100	8		
80	5	2.0	1/39
70		1.5	1/45
60		1.0	1/50
40	4.5		

The distance is the absolute distance from the eye, the limen the difference in distance that can be just noticed, the relative limen, the limen for binocular vision divided by the absolute distance. This it will be noticed is approximately the same as the difference limen for the comparison of horizontal lines on a flat surface, in which movements have also been regarded as playing an important part.

Double Images in the Perception of Distance. — Still another indication of the distance of objects is given by the differences in the images of the objects on the two retinas. One may be said to get a different image of a distance with each eye. If one hold a ruler end on in front of the eyes and close first one eye and then the other, it will be noted that the image shifts as the eyes are changed. If one converges upon the far end, the near end will be seen double with both eyes open, while if one looks at the nearer end, the farther will be double. In either case the image of the ruler will slant from the double to the single end. These double images will not be noticed at first but will be used as immediate signs of the distance of one end from the other. Similarly, if two threads are present simultaneously in the field of vision at different distances, the one fixated will be seen single, the other double, and will be separated by a space that increases with the distance between the threads. This doubleness is of value only in determining the distance between two objects or points, not for the determination of the absolute distance of a single object. The degree of doubleness changes with each position of the eyes as well as with the distance of the object. Given the ab-

solute distance of any point of reference, the distance of any other point from that in the field of vision may be

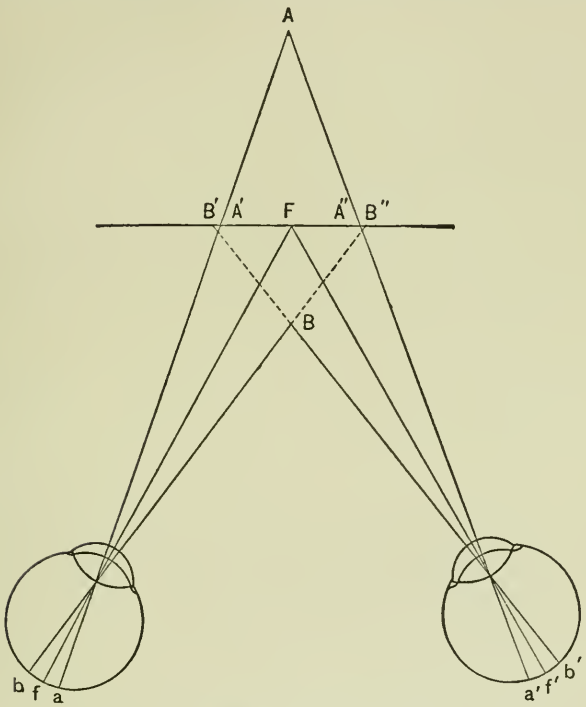

FIG. 72. — To illustrate crossed and uncrossed images. *F* is the fixation point and is seen singly. A more distant point *A* is projected upon points *a* and *a′* on the retinas, which are non-corresponding. As excitations of the retina are projected to the plane of the fixation point, they are seen at *A′* and *A″* and are therefore uncrossed, the image seen with the right eye is seen to the right of the fixation point and to the right of the image seen with the left eye. Objects nearer than the fixation point, as *B*, will also be projected to the fixation plane at *B′* and *B″* and so are crossed, the image on the right retina is seen as if it were to the left of the fixation point and *vice versa*.

determined. Not only may the distance between two points be determined in this way but also which is nearer.

If one fixate the more remote, the double images are crossed; that is, the one on the right is seen with the left eye, and *vice versa*. If one fixate the nearer, the more remote gives uncrossed double images. This can be tested by closing one eye. It will be noticed that when the farther object is looked at and one eye is closed, the image on the opposite side disappears; when the nearer object is fixated, the image on the same side disappears. This comes because the double images are always referred to the plane of the fixation point in considering their relative position as on the right or on the left. This can be seen by study of the diagram (Fig. 72).

These double images constitute one of the important features in estimating depth in our ordinary perceptions. As one looks at any landscape with the eyes converged upon some object in the middle distance, all nearer objects are seen double in crossed images; all more remote objects are seen double in uncrossed images, and the degree of doubleness increases with the distance from the object fixated. These double images are not ordinarily seen for themselves, but are at once translated into distance, just as are the strains of accommodation and convergence. However, they can be noticed with a little practice. So close has become the association between double images and the perception of distance that when letters are printed to appear double, they seem nearer or farther even when viewed with a single eye. The importance of the double images may be shown by the use of the ordinary stereoscope which depends for its effect upon the fact that the two pictures represent the image that would be seen, one by the left,

the other by the right eye, were one standing at the point occupied by the double camera when the picture was taken. The prisms in the stereoscope turn the rays of

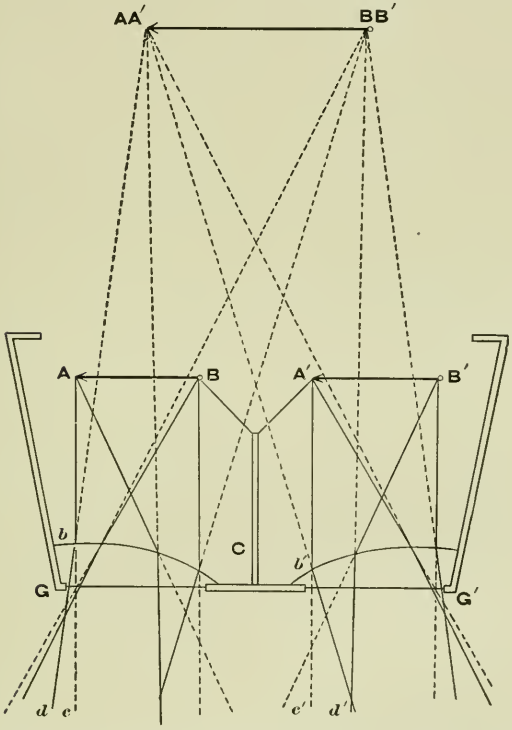

FIG. 73. — Diagram of prism stereoscope. (From Titchener, "Experimental Psychology.")

light sufficiently to have them enter the eyes as if they came from a single object rather than from two. The difference in the two pictures gives the same degree of doubleness that would be given by the single object, and

is interpreted as distance just as it is in actual space perception. Increasing the distance between the cameras that take the pictures increases the apparent depth.

Pseudoscope and Teleostereoscope. — Even more striking is the effect of the pseudoscope. If the relations of the double images are reversed, as may be done in the stereoscope by substituting the picture belonging to the right eye for that belonging to the left, the nearer objects appear farther away, the more distant nearer than the point of fixation. The same effect may be obtained with real objects by using the pseudoscope devised by Wheatstone. This consists of two right-angle prisms mounted in tubes that can be brought one before each eye. The images are reversed in passing through the prisms, and this makes the images that come from the nearer object enter the eyes as if they came from the more remote; the character of the double images is reversed, those from objects more remote than the fixation point are crossed, those from objects nearer than the fixation point are

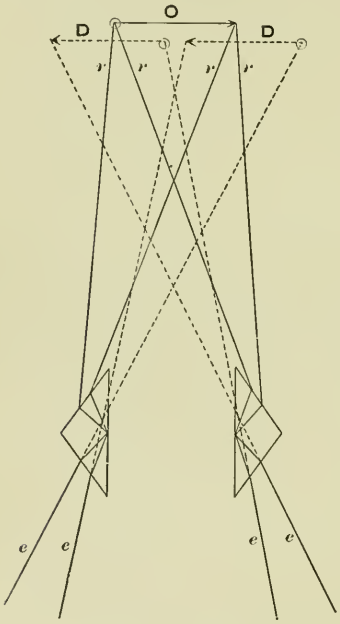

FIG. 74. — Diagram of prism pseudoscope. (From Titchener, *op. cit.*)

uncrossed. In consequence, the distance interpretations are also reversed. The inside of a mask when viewed through the stereoscope will appear to be the outside, the nearer of two threads will seem to be more remote, etc. It is to be noted that the effect is much easier to obtain if the inside of the mask be painted to represent the outside and is so lighted as to avoid strong shadows. Another indication of the importance

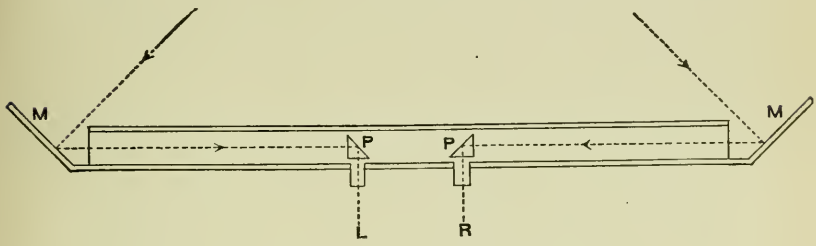

FIG. 75. — Teleostereoscope. (From Titchener, *op. cit.*)

of double images in the perception of distance is furnished by the teleostereoscope. This instrument consists in principle of two pairs of mirrors, *P*, *P*, one before each eye, and another, *M*, *M*, at a little distance to the outside to receive the rays of light from the object. The effect is to increase the degree of doubleness and to make the perception of distance as accurate as it would be if the eyes were as far apart as the more widely separated mirrors that first receive the rays of light. The course of the rays may be made out from the figure. A similar device is used in the better field glasses at present. Surfaces of prisms supply the mirrors and these are separated by a much smaller distance to make the instrument more portable, but they serve to increase markedly the accuracy of the estimation of distance.

These three factors, the strain of accommodating the eye to see different distances, the strain of converging the eyes upon an object, and the double images, constitute the signs of depth that may be said to depend upon the structure of the organs, and are sometimes called the primary factors. They vary in accuracy, — accommodation is least accurate, convergence about five times as accurate, and double images much more accurate than either of the others. They also vary in the distance at which they are effective. Accommodation varies for objects that are nearer than fifty feet, convergence up to about 300 feet. Under the best conditions double images give an idea of distance up to about 2500 yards. Beyond that, the more distant objects show no appreciable double images, although of course all nearer objects are seen as double. In each case the distance alone is really seen; the strains or double images that have been mentioned are not noticed. The distance directly inferred is not any single mental image or sensation, any more than is the local sign, but is appreciated as just distance.

The Psychological Factors. — While these primary factors are most accurate, many other signs of distance are of great value. The others consist of changes in the character of the image as the distance changes. They are the secondary or psychological factors. Perhaps the most important of these is perspective. The size of an object is inversely proportional to the distance. If one knows the size of any object in the field of vision, it is altogether possible to infer its distance from its apparent size, the size of the image. The im-

portance of this means of obtaining an idea of distance may be gathered from the use of perspective in art. The distance ascribed to an object in a photograph or painting depends very largely upon its size, relative to other objects in the photograph. Here as in the other factors the estimates of distance are not made consciously, one does not first notice the diminished size and then infer how far away the object must be to give that distance, but sees the distance at once and corrects the size of the object in accordance with his estimate of distance. The object seems to be of full size and at the correct distance. The tendency to overlook the difference in size is evident from the relatively late development of perspective in art. The early paintings and bas-reliefs make distant objects of the same size as the nearer ones. Obviously the early artist had not noticed the phenomenon of perspective but inferred distance without knowing how. Even now an artist often draws his distant objects larger than they should be.

A second factor under this head is the higher position of more distant objects in the field of view. Objects on a flat ground plane appear to rise gradually as they go away from the eyes and, with proper allowance for the actual height of the object above the ground plane, the relative height may be used as a measure of distance. This factor was recognized by the early artists. Their distant figures are placed higher than the nearer, an arrangement that makes it possible to show the more remote, as well as to imitate the apparent effects of distance. The haziness or distinctness of objects is also an important factor. This can be seen from the tendency

to mistake distant objects for near where the air is particularly clear. In theatres it is customary to draw a net in front of the more remote parts of the scene. Distant objects also are blue. Both of these effects are due to the absorption of light waves by the air intervening between the object and the observer. The condition is sometimes called air perspective. An element almost too obvious to mention, but nevertheless highly important in practice, is superposition. The partly hidden object must be more remote than the one fully seen.

Motion an Aid to Distance Perception. — Motion, both of the observer and of the object, plays a part in the perception of apparent depth. When the head is moved to one side, all objects in the field of vision are displaced in different degrees. If one is looking at any object in the middle distance, all nearer objects shift in the direction opposite to the movement, all more remote ones in the same direction. The amount of the apparent displacement increases with the distance between the object and the fixation point. When one is in rapid motion as in a railway carriage or an automobile and is looking at a point in the middle distance, there is a constant procession of the near objects backward and the more remote objects forward, at a rate that depends upon their distance and the rate of motion. This gives a notion of distance. When objects are themselves in motion, the apparent rate of motion compared with the usual rate of the object at a standard distance serves as an indication of its distance. When seen from a rapidly moving vehicle objects seem smaller than usual because they seem to be moving much more rapidly than usual.

This means that they are regarded as much nearer than they really are, and this by the habits of perspective means that they should be interpreted as small.

Shadows in Space Perception. — Another factor that aids in determining the form of objects in the third dimension is the interpretation put upon shadows and high lights. The nearer surfaces are usually well illuminated while the more remote are more or less in the shadow. This is translated at once into depth or distance and the shadows themselves are little noticed. Shadows are much used by the artist, in fact are quite as important as perspective in enabling him to represent depth in the contour of an object on the flat canvas. In the real object much depends upon the knowledge of the direction from which the light comes or from assumptions that are made concerning the direction. If one will look at a cameo under a microscope which reverses the image, it seems to become an intaglio. The high lights fall on the side that they would have were the depth relations reversed, and with that they are seen as if reversed. In depressions made in steel by a smooth ball where the lights are coming from all sides and the reflections are numerous, it is quite easy to see the depression as a protuberance.

Depth for vision, then, is appreciated by virtue of a number of differences in the sensations that come from the muscles of the eye, external and internal; in the difference in an object as it is seen by the right eye and by the left; and by a number of peculiarities of the image of an object that change with the distance. These sensations are not first seen for themselves and then asso-

ciated with the idea of distance; there is no conscious use made of them in estimating distance, but as a result of their presence the object is at once seen at the corresponding distance. In this respect the third dimension is, like the other two dimensions and the idea of position, apparently received immediately and can be analyzed into its elements only indirectly.

Auditory Perception of Space. — One other sort of perception of distance needs to be mentioned, the perception of the position and distance of sounds. Unlike tactual and visual sensations, there is in sound no really two-dimensional space, no perception of objects in contact with the sense organ, but merely perception of the distance and direction of objects that give rise to sounds. These localizations are relatively uncertain and indefinite. One is constantly deceived as to the distance and direction of sounds. The breathing of a dog on the hearth may be mistaken for distant thunder or some other intense but distant noise. Front and back are often confused. Right and left much less often, but still under the influence of suggestion, confusions of this sort are far from infrequent. Experiments indicate that the primary factor in the perception of distance is the intensity of the sound as compared with the sound given at some known or standard distance. This implies, first, a recognition of the source of the sound, then an association between the present intensity of the sound and the distance that would give the particular intensity. A locomotive whistle has been heard at a large number of distances, more or less accurately observed or measured. When it is recognized,

its intensity at once suggests the distance. Similarly with any familiar sound. If the sound be altogether unfamiliar, recognition of distance would be difficult, although if it be recognized as belonging to some known class, an estimate can usually be made.

The Appreciation of the Direction of Sounds. — Perception of direction depends upon three factors, — the relative intensity of the sound heard with each ear, the timbre of the sound, and its intensity. A sound on the left will excite the left ear more than the right. Some more accurate notion of the direction of the sound may be gathered from the relative strength of the effects upon the two ears. Distinguishing between before and behind offers greater difficulties. With pure tones it is almost impossible. If two tuning forks of the same pitch be vibrating, one directly in front, the other directly behind, and one be stopped, it is almost impossible to tell which is still sounding. The percentage of mistakes will approach fifty. If the sounds be complex, are noises, or from instruments rich in overtones, fewer mistakes are made. This suggests that the quality of the tone is in some way modified by the direction from which the tone comes. Angell asserts that this may be due to the way in which the various overtones are modified when the tone strikes the outer ear. From one direction, one overtone or group of overtones will be reënforced, from another direction another will be strengthened, and the resulting complex tones are interpreted as meaning direction. Myers [1] has shown experimentally that changes in the timbre of a tone will induce changes in

[1] C. S. Myers, Proc. Royal Society. B. Vol. 88, 1914, pp. 267–284.

localization. If a tone be sounded directly in front until the observer has acquired practice in localizing, and then the component parts of the tone be changed to give it a different quality, the sound, although still coming from in front, will be localized in some other position. Changes in the intensity of the sound also induce similar mistakes. The importance of the changed intensities is to be related to the fact that sounds from in front are caught by the pinna, the outer ear, and focussed into the meatus, while sounds from behind are diminished in volume. When the absolute intensity and the distance of a sound are known or may be conjectured, the position of the sound as in front of or behind the plane of the ears can be appreciated in terms of intensity. Direction of sounds, then, is estimated by means of the relative intensities of the tones as heard by the two ears, and by the timbre and intensity of the tone. It has at times been assumed that direction might be known by means of the stimulation of the skin in the neighborhood of the ears, or on other portions of the face. This assumption is improbable in itself, since sound waves are not sufficiently intense to excite the organs of pressure. Myers found, too, that when he placed short rubber tubes in the ears, all capacity for estimating the position of sounds disappeared. These tubes made it impossible for the external ear to modify the quality of the tones or their intensity but left the tactual sensations unaffected. Were the skin to play any part in the determination, the tubes should have had no influence.

The Auditory Space of the Blind. — Auditory appreciation of space plays a much larger part for the blind,

who must trust to the ears for a knowledge of the position of all distant objects. A blind man appreciates the distance of objects fairly accurately through the effect they have upon the quality of familiar sounds, such as his footsteps or the tapping of his cane. Large objects reflect the sound, give echoes, or modify its quality. It is easy to distinguish the difference in the voice when

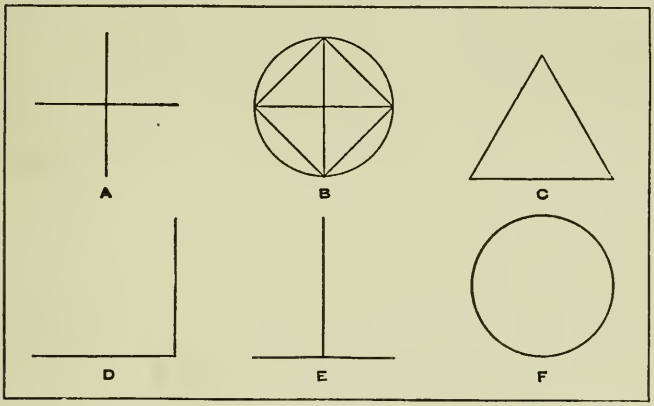

FIG. 76. — Illusions due to overestimation of the vertical. (From Titchener, *op. cit.*)

speaking in a room filled with people and when speaking in an empty room. Even the presence of furniture in a room in an ordinary dwelling has a pronounced effect. The blind man learns to distinguish all of these differences and to learn what they mean as to the presence and arrangement of objects. That the blind depend upon the reflection of sounds in avoiding objects was shown by Dr. Heller,[1] director of a blind asylum, who on one occasion provided his pupils with felt slippers

[1] Heller, Studien zur blinden Psychologie.

in place of their heavy shoes and watched them at their play. He found that they no longer avoided obstacles and would come into conflict with many of them. The sound from their footsteps could no longer be heard

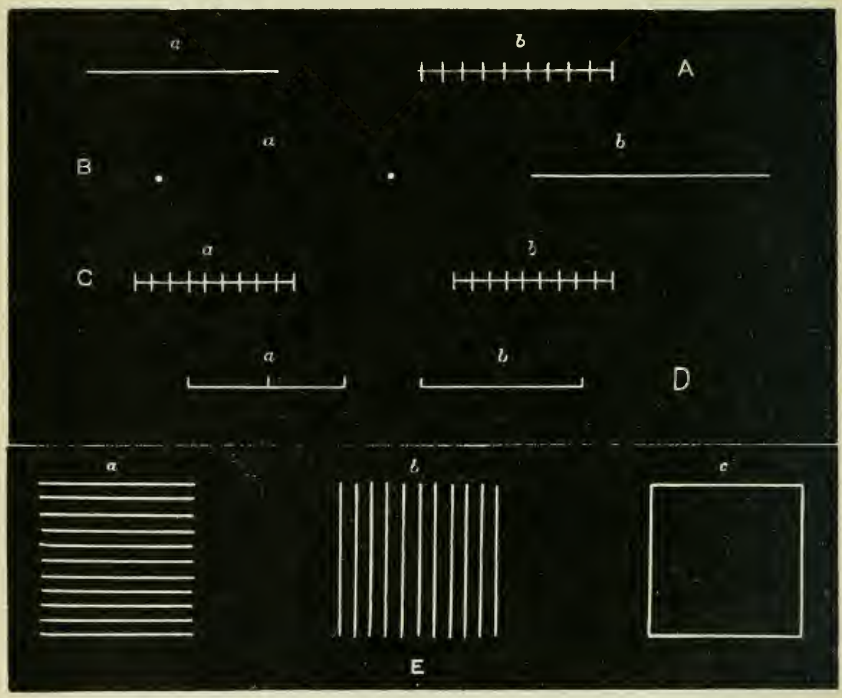

FIG. 77. — Illusions of filled and empty space. (From Titchener, *op. cit.*)

sufficiently for the modifications by the obstacles to be noticed. It seems, then, that for the blind much of the perception of space depends upon the modification of the sounds of the footsteps and of other familiar sounds by walls and objects in general.

Optical Illusions. — Very interesting as illustrating the factors that lead to the perception of space and of perception in general are certain illusions of visual space perception. Many more forms of optical illusion are known than we can describe, and more explanations have been offered than we have room to mention, but we may select a few illusions as illustrations of the more important theories. One of the simplest types is seen in mistaken estimates of the length of lines or distances between dots. Thus horizontal lines seem shorter than vertical lines of the same length (Fig. 76, *A*, *D*), interrupted spaces seem longer than uninterrupted or unfilled spaces or lines. Figure 77, *A*, *B*, indicates that filled space, space filled with a number of dots, or a solid line seems longer than the empty space of the same length; Figure *E*, that a square with numerous vertical lines drawn across it seems longer than it is high. Even these simple illusions have given rise to much difference of opinion. One theory would explain all in terms of eye movement. It is said that the fact that the up and down movements of the eyes involve a waste of effort, owing to the tendency of each superior and inferior rectus muscle to pull the eye in as well as up, a tendency which must be counteracted by the oblique muscles and so gives rise to greater amounts of strain, leads to the overestimation. Experiments made with the observer lying on his side which show that the vertical distance is still overestimated would tend to disprove this theory. Helmholtz suggested that the overestimation of the vertical was due to a habit derived from the use of perspective. Vertical lines in space, as in a picture, usually or fre-

quently represent greater horizontal distances seen in perspective, and so we form the habit of overestimating all vertical lines.

According to one theory the interrupted spaces are made to seem longer by a similar exaggeration of the apparent movements through the numerous stops that are made at each of the intervening dots or lines. That this is not the whole story can be seen from the fact that where the dots are relatively few (Fig. 77, *D*), one or two only in the length of the line, the distance is underestimated rather than overestimated. The other explanation is that the filled spaces give an impression of multiplicity and this is confused with the length of the line. The apparent shortening of the line when only one or two dots are inserted is apparently due to a confusion between the separate spaces and the total length. The full line tends to be compared with the smaller divisions of the divided line. This same confusion is better illustrated in the comparison of the vertical and the horizontal lines in Figure 76, *E*. Here the vertical is compared with the halves of the base line. Where erected at the end of the line, the vertical is slightly overestimated but relatively very slightly (Fig. 76, *D*). This effect can be eliminated by turning the book ninety degrees, while the illusion in *E* persists.

The Müller-Lyer Illusion. — One of the most striking and most discussed of all is the Müller-Lyer illusion. It will be noted that the line, bounded by oblique lines that turn in, seems much shorter than the other line of the same length bounded by oblique lines that turn out. The explanations offered for this illusion include

practically all that may be offered for any. Wundt suggested that it was due to eye movements, that the eyes were checked too soon by the lines that turn in, and carried on by the lines that turn out. It is suggested that it be explained on the basis of perspective, that one

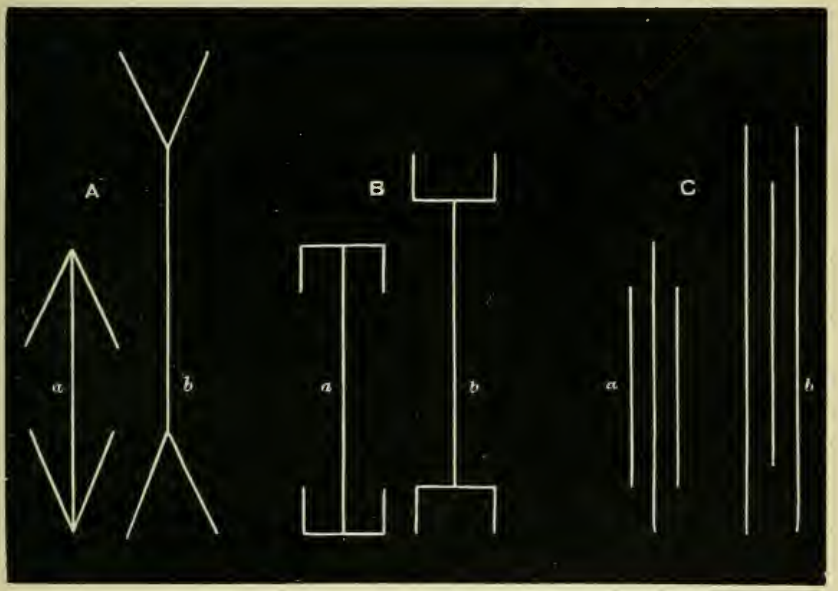

FIG. 78. — Various forms of the Müller-Lyer Illusion.

represents an open book or similar figure with the back towards the observer, the other an open book, much larger, with covers opened towards the observer. In the first case the actual length of the book is the length of the line itself; in the other, the length would be from the end of the oblique lines at their greatest separation. Still another theory is that one confuses the whole spaces

between the oblique lines with the horizontal lines and really makes a judgment of the spaces, although it is assumed that the lines are being compared. This is one application of the so-called theory of confluxion and contrast. This would be an instance of confluxion or

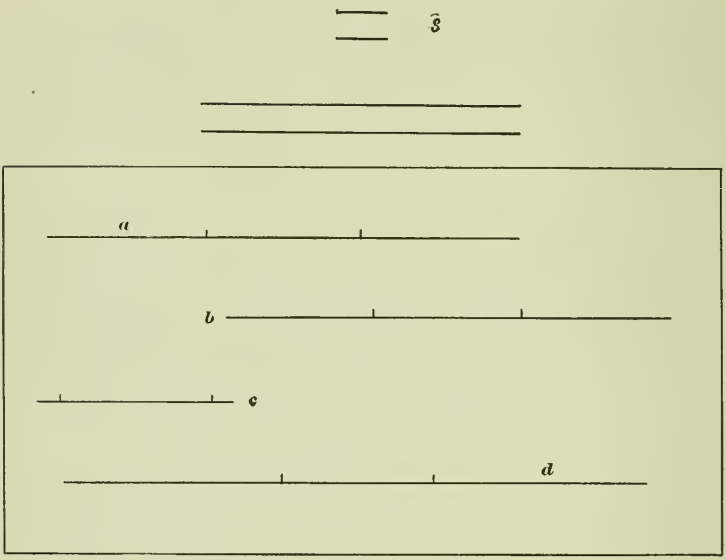

FIG. 79. — Contrast illusions. (From Titchener, *op. cit.*)

of the tendency to confuse something in the surroundings with the part of the figure that is to be judged.

The eye-movement theory is in this case rather far-fetched. Dawes-Hicks found that the illusion persisted when the figures were exposed for too short a time to permit the eyes to move. And while Judd found that moving pictures taken of the eyes while the figures are being compared showed movements that in many

instances correspond to the illusion, he concluded that the movements are due to the illusion rather than

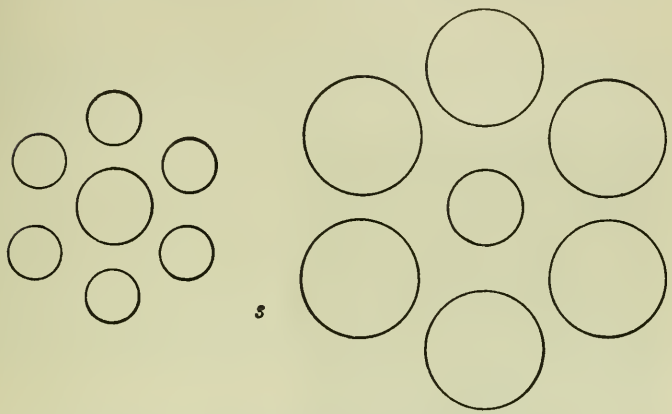

FIG. 80. — Contrast illusions. (From Titchener, *op. cit.*)

the illusion due to the movement. The perspective theory serves to correlate a number of different illusions and may have some influence, but is hardly to be regarded as the only explanation. In a wide sense, the confluxion theory comes to mean that factors, other than those immediately compared, play a part in determining

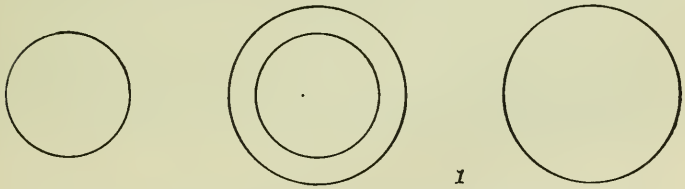

FIG. 81. — Illusion due to confluxion. (From Titchener, *op. cit.*)

the comparison, and in this form would include the perspective element as well as any other considerations

that might aid in controlling the judgment. On the whole it more nearly corresponds to the facts.

Illusions of size that illustrate the effect of contrast are seen in the lines of Figure 79 and the circles of Figure 80. The distance between two short lines seems much longer than one of the same length between two long lines. Much the same effect is obtained with the circles. In Figure 81, the two circles when put together to form a band seem the one larger, the other smaller, than when separate. When together, each approximates the size of the centre of the band and so tends towards the average (confluxion). When a circle is surrounded by a series of very small circles, its size increases as compared with the same circle near a single much larger one (Fig. 80).

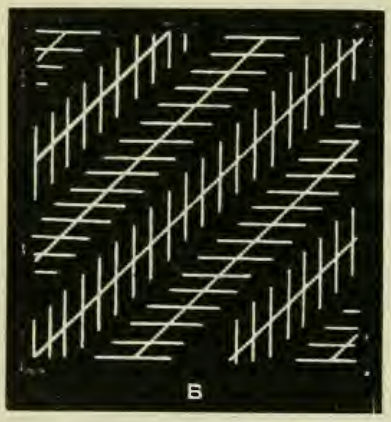

FIG. 82. — Zöllner's Illusion. (From Titchener, *op. cit.*)

Angle Illusions. — Illusions of direction are also numerous. They may be illustrated by the Zöllner illusion (Fig. 82), the Hering figure, the Wundt figure (Fig. 83, *A* and *B*), and the Poggendorf figure (Fig. 84). The eye-movement theories, the perspective explanation, and confluxion have all been used as explanations. The eye-movement theory holds that the eyes are distracted by the cross lines, but why they should be is not made

particularly clear. The perspective theory may take two forms. Each of the first three figures may be seen

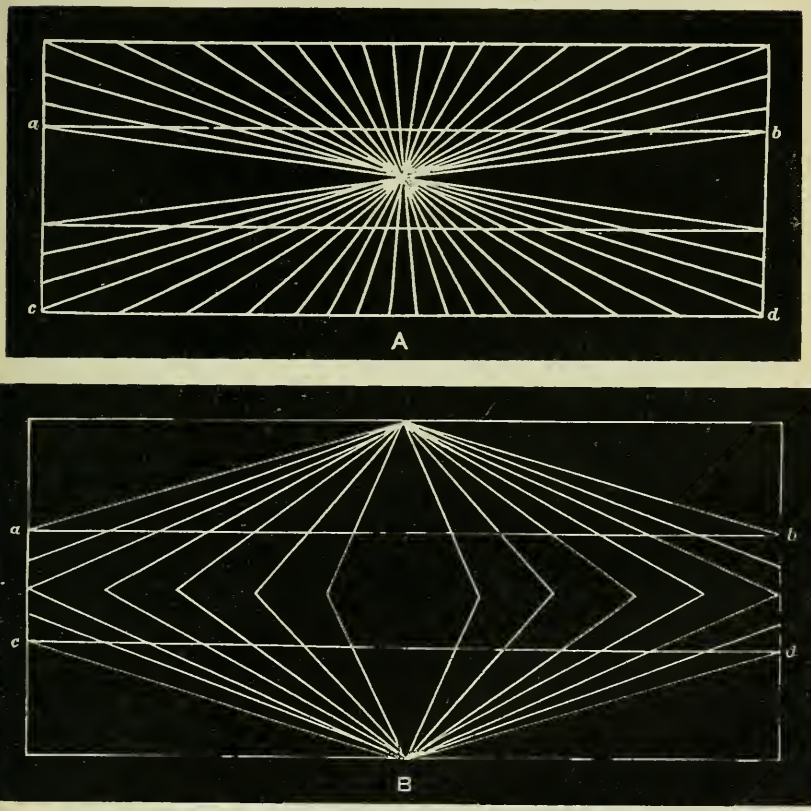

FIG. 83. — Hering's and Wundt's figures. (From Titchener, *op. cit.*)

as if drawn in perspective, and as the parallel lines do not converge as they should to harmonize with the perspective, it is assumed that they must diverge. Still another application is that the whole figures may

be explained as due to the overestimation of acute angles and the underestimation of obtuse angles. It will be seen that this is what really happens in each case. But it may be said in addition that the estimation of the angles is made on the assumption that whenever two lines cross at right angles and are distorted by perspective, the figure represents two lines crossing at right angles as seen with the horizontal line in an oblique plane. This can be made out in Figure 85, where the two lines can easily be imagined to represent two lines crossing at right angles. Since all angles made by straight lines are likely to indicate right angles seen in perspective, we have acquired the habit of overestimating acute and underestimating obtuse angles. The Poggendorf illusion readily falls under this explanation. The lines do not meet because each is turned toward the horizontal, and they are turned toward the horizontal by the overestimation of the small angles; or to go back to the explanation of that tendency, one inclines to see it as if it were really more nearly perpendicular to the vertical line.

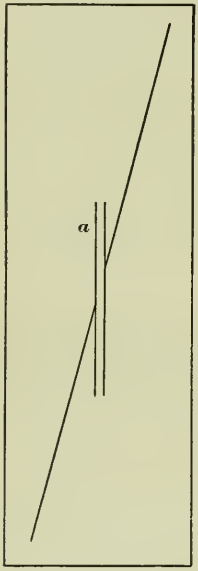

FIG. 84. — Poggendorf's Illusion. (From Titchener, *op. cit.*)

These illusions, then, are all due to the fact that interpretation tends to become mixed with sensation and that one cannot keep attention fixed exclusively upon

the essentials of the figure but is misled by its surroundings. Mixed with the confusion of part with the whole is always the tendency to see what the figure means rather than the figure itself, and to believe that it means something different from what is actually represented. The various special theories, perspective, confusion, or

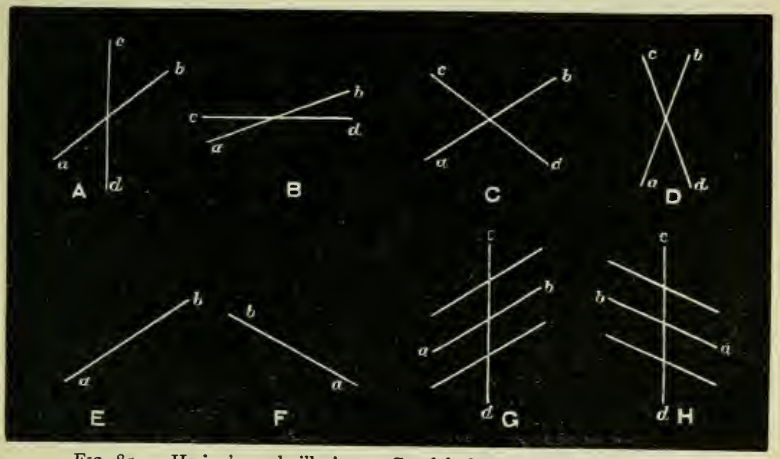

FIG. 85. — Hering's angle illusions. Careful observation shows that any of the oblique lines may be interpreted as crossing in some other than the plane of the other line. (From Titchener, *op. cit.*)

confluxion, even eye movements, are but special forms of this general tendency.

General Theories of Space Perception. — A more abstract problem naturally arises at the end of a statement of the particular facts of space perception, the question what is space itself. Two schools have contended over this question since the beginnings of modern philosophy. One, the nativistic school, insists that the capacity to appreciate space is born with us and may be used without

preliminary practice. It may be dependent upon inherited characteristics of our nervous system, or may be an original mental activity. The other school, the empirical, asserts that space is developed through experience, — must be in some way derived from the conditions of perception. For the first, space offers no problems; it is appreciated at once, as color is appreciated. For the empiricist it is necessary to discover the components of the space idea and also to determine how a particular space idea is suggested. The concrete evidence for neither position is very definite. The empiricists point to the numerous cases of error in judgment, and the cases in which appreciation of space may be shown to depend upon definite sensations and particular associations. The nativist contents himself with the statement that the factors that the empiricist asserts compose space are altogether different from space as we know it, and also that it is inconceivable that space can be derived from anything not itself spatial.

FIG. 86. — The transformation of right angles in natural objects seen in perspective.

The Space Discrimination of Those Born Blind. — The problem cannot ordinarily be approached directly, since the child has already developed his notion of space before he is able to tell us about it, and adults have long since forgotten what their first experiences were like and how they developed spatial ideas. Already in the seventeenth century, Locke suggested that if one could find a man who had been born blind and

recovered his sight after he became able to describe his experiences, it would be possible to say how much of space perception was innate and, if not innate, how it was acquired. Since then a fair number of cases of this sort have been observed. The lens of the eye is occasionally opaque from birth and may be removed by an operation, and the patient may be made to see. There is no great agreement as to what the patient can see, but the following statements seem to be in harmony with most results. The shape of objects is not recognized at all. One patient could not tell a square from a circle until he had had a chance to touch each. The field of vision is described as a confused mass in which everything seems to be in irregular movement. Some patients seem to notice the difference between geometrical figures when they cannot say in what that difference consists. One, after being told what an angle was, could count the angles on a figure and thus distinguish a triangle from a square, but for some time afterwards was not able to distinguish without this counting. The perception of distance was always defective. Objects seemed in most cases to touch the eye and in no case were they projected beyond the reach of the patient. There is practically no appreciation of depth. Neither school is altogether convinced of the falsity of its own position by the evidence. The nativist argues that the patient sees so little because he transfers the associations developed by touch to sight. The patient thinks objects must touch his eyes because they touch his skin. The empiricist, on the contrary, argues that the patient would see nothing were it not for this same earlier experience,

that interpretation from tactual experiences and from the light that comes through the lenses before the operation makes possible even the imperfect spatial judgments that are made.

The attempts made by the empiricist to explain or analyze the spatial experience have for the most part consisted in reducing the various forms into some single one. Movements or memories of movements are most frequently asserted to constitute true space. Double images, on the theory, give an idea of depth because they call up the memories of old movements of convergence or of the reaching movements required to obtain the object. That such transfers from one sense to another do take place is readily observed. Most persons use a visual space, although a motor-minded individual may translate visual and tactual distances into kinæsthetic terms. But, after all, translation from one space to another does not solve the problem of space. No one sense gives a more direct and intuitive knowledge of space than any other. Vision is probably more delicate in its appreciation, while movement demands an accuracy in space estimates to be adequate, but it cannot be said that the accuracy of the one or the needs of the other constitute it the intuitive space sense.

We may reduce the problem of the origin of space to its lowest terms if we see that there are three essential elements in the spatial experience. These are the sensation or sensory cue, the idea or notion of space, and the association between them. The sensory cue always is present before the idea can be suggested. Contact on a spot calls up the idea of position; double images,

strains of accommodation, and convergence suggest the distance. The question whether it is innate or derived from experience may be considered for each separately. We may assert at once that the connection is derived through experience. Illusions show that the associates may be misplaced — the wrong idea may be called up by any cue, — and an innate capacity to make mistakes is not desired by the most ardent supporters of that theory.

The most that can be innate is the stimulus or cue and the idea of space that it calls out. That the exciting cause is a bare sensation or sensory stimulus which depends upon the physical structure of the sense organ or the nervous connections and in this sense is innate, no one will deny. The case for the idea is not so clear. Whether this be innate or derived is the real crux of the problem. The argument that it is derived must give over any attempt to reduce it to a single element or even to a combination of different elements that preserve their original character. Space cannot be movement, it cannot be sight or touch. Judd has suggested that it is not a movement but an organized system of movements in which the various contradictions have been removed and suited to all possible occasions for action. If we accept this statement as far as it goes, we must add to it that space is an organization of experience as a whole, sensory as well as motor, and that there results from it not movement, but a concept or notion which not merely prepares for action but makes it possible to represent all spatial experiences consistently and harmoniously. We may use it for our estimates of space, as well as in the control of move-

ments, — for the combinations of the mathematician as well as for the actual structures of the engineer. What the actual content of this idea is cannot be asserted. Like most concepts, it is more important for the things it represents than for itself. It probably varies in many respects from individual to individual. It is certainly more highly developed for the mathematician than for the common man, and more highly developed for the adult than for the child, for the civilized man than for the savage. The process of development has probably been to accept some simple idea or even sensation and to use it until contradictions appear. These are obviated by changing the notion until something that avoids the difficulties is hit upon, and this is again changed as occasion arises. The concept always grows out of practical needs, whether sensory or motor. Thus images on the retina are given a size that can be most readily fitted into our conception of the field of vision as a whole. Small objects are usually seen as if they were at about arms' length or where they can be easily manipulated, houses at a distance that gives us a good view of them; and in thought these various typical distances or sizes are used in place of the sizes of the images on the retina. They are what are called the real sizes of the objects. Similar notions develop for position, for extent, and for depth. They are changed and adjusted until they satisfy the conditions of movement, of sight and touch, and of the practical and theoretical needs of every sort. In the final concept little if any trace of the particular ideas need be left, certainly nothing that can be analyzed out of the concept by direct

introspection. It represents the various experiences as corrected by different tests, but it is not compounded out of them. Our choice as to the real nature of space lies between these alternatives of assuming on the one hand that it is a concept that has developed out of experience by innumerable trials that finally give rise to a system of ideas that will satisfactorily represent space, and of assuming, on the other hand, the nativist position, that space is given once and for all and that we certainly cannot explain it. We can at most watch its development. The former seems to the writer to offer the possibility of a real explanation, the latter at most gives up the question as insoluble.

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CHAPTER IX

PERCEPTION — VISUAL MOVEMENT, OF TIME, AND THE GENERAL LAWS OF PERCEPTION

Visual Perception of Movement. — How the eye appreciates movement is a problem closely related to the perception of space; in many ways it is intermediate between the perception of space and of time. Two forms of movement must be distinguished, one in which the movement can be actually seen, and a second in which movements are so slow that one infers that the object has moved from the fact that its position changes between two observations. The movements of a meteor belong in the first class, that of the sun in the second. The slowest rate that can be really seen is one angular minute per second. Movements may also be too fast to be seen directly. An electric spark moving more than 15″ in a thousandth of a second cannot be seen to move. Nothing more is seen than the path. How we perceive the movement of objects at the intermediate rates offers a definite problem, but one concerning which theories are in conflict. Three different theories may be mentioned. The first holds that the eye follows the moving object, and that appreciation of the movement of the eye gives also a knowledge of the movement of the object. This theory is very direct but depends for its acceptance upon proof

of ability to appreciate the movement of the eye muscles. Recently, various bits of evidence indicate that movements of the eye muscles are much less accurately known than has been sometimes assumed. In the first place, there is little accuracy in estimating the movement of an object when it stands alone in the field of vision. A faint light moving in the dark may seem to move much more slowly than it really does, and on the contrary a stationary light may, under those circumstances, seem to be moving. If two faint lights are attached to the ends of a rod swinging from a point near its middle, either light may seem to move while the other is stationary, or the motion may be divided between them in any proportion. When only two lights are in the field, one sees the relative but not the absolute motion. When stationary objects are in the field, it seems that the movement of objects is determined by their relation to the fixed objects in the field of view, rather than by following the object with the eye and appreciating the movement through the contraction of the muscles.

The After-image Theory. — Stern, among many other writers, has suggested a second theory,— that movements are appreciated through the after-images that the moving object leaves upon the retina. Watch any object in fairly rapid motion and you will notice that it leaves a trail of after-images as it moves and that its course can be distinctly made out for a few moments by means of this trail. The motion of the moving picture is due, on this theory, to the fact that the separate pictures of the object also leave a line of after-images and that

these are interpreted to mean motion. The motion seems continuous if the separate images succeed each other with an interval of no more than fifteen thousandths of a second, a rate much higher than that ordinarily used in exhibitions, fifteen to twenty per second. If this theory be applied to explain the differences between the three kinds of motion, movements too slow to be seen must leave no after-image that can be noticed, while in movements too fast to be seen, no distinction can be made between the after-image and the primary stimulation. The whole course is of approximately the same intensity. The after-images also give a means of determining the course of the motion. They are more intense near the stimulus and grow gradually fainter the greater the distance from it. After-images, then, are interpreted as motion, and the direction of the motion is assumed to be from faint to vivid images.

After-images of Movement. — That motion itself has an after-image is an important fact for the theories of movement, and its study has contributed much to the explanation of movement in general. If one look for several seconds at any moving surface, the paper on a kymograph, a stream, or at a revolving spiral, and then look away at a stationary surface, there will seem to be a movement in the opposite direction. Two explanations of this phenomenon have been offered; that it is due to the reversal of the after-image, and that it is due to an actual displacement of retinal elements by the motion, followed by their return to the original position when the movement ceases. Visual after-images change from positive to negative shortly after the stimulus

is removed, as will be remembered from an earlier chapter. If in the original motion the after-images near the object are dark, and the more remote brighter, in the negative after-image the dark portion will become bright, shading off to a darker region. A negative after-image of brightness would give an apparent reversal of the movement.

The Theory of Retinal Streaming. — That the perception of movement and the reversal of direction in the after-image are due to actual movement of elements in the retina has been asserted for some time and has been strongly supported recently by Ferree and Hunter. This is our third theory of the perception of movement. The evidence in its favor is the great vividness and persistence of the sensory processes, particularly in the after-image of movement. These observers assert that when the after-image of motion is well developed, there seems to be a veil of objects streaming over any surface looked at, and that it would be impossible for after-images or any of the other factors suggested to persist long enough or to be sufficiently realistic to account for the effect noticed. On the other hand, they admit that what we know of the retinal structure gives no evidence in favor of an actual movement of its elements. Altogether the after-image theory seems more plausible. After-images are known to exist and must play a part in the perception of motion. The only question is whether they account for all of the observed phenomena. We may at least accept it as the most probable theory at present for the explanation of all perception of movement.

Granting that the problem of how we see movement at all is settled, it is still necessary to consider how we distinguish between possible interpretations in actual movements. Many of the phenomena may be the result of several different conditions in the outer world. Either the eye or the field of vision may be in motion when many objects are leaving after-images. We may distinguish three conditions of motion if we consider only the movements of objects and of the eyes. The eye may be stationary and one object in motion; the eye may be in motion, following one object, perhaps, while the rest of the field is stationary; or, finally, the eye may be following one object while other objects are moving in different directions or at different rates. The first case has been discussed above. In the second case one would have a clear image of the object that was pursued by the eye, while all other objects would be seen in blurred images or would be leaving after-images. Here we must explain how we know that the eye is moving. This might be, either through the sensations from the eye muscles, or by the after-images or other signs of movement developed on the retina by stationary objects. The clear image of the object in flight would show that it was being properly followed, while the after-images of all other objects serve as an indication of the movement of the eye. Still more complicated, but nevertheless capable of explanation along the same lines, is the problem offered when the object and eye are in motion in different directions or at different rates. Here the total estimate is based on a comparison of the movement of the eye with the displacement

of the image. In each of these cases much depends upon the estimate of the probability of movement. Even when it is a question whether the motion is of the external object or of the observer, interpretation plays a large part. If one stands on a bridge over a rapidly running stream, it is quite easy to ascribe the motion to the bridge. The probabilities in the light of frequency of occurrence are that a small object like a bridge will be in motion rather than the larger river. Similarly, when you are on one of two trains standing in a station, and one starts, motion is ascribed to one or the other in accordance with your expectations. Not merely the sensory elements that give the perception of motion must be taken into account, but also the estimation through early experience of the probability that the object is or is not likely to move.

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RHYTHM

Most series of excitations which repeat themselves at short intervals tend to fall into rhythm. Rhythm needs no description, and one could not be given if demanded. Two factors may be distinguished in rhythm, the grouping of the single elements into units, and the accenting or emphasizing of one or more of the

units. Auditory and kinæsthetic impressions show rhythm most easily, tactual and visual, not so markedly. The accentuation in rhythm may be produced in a number of different ways and still give the same effect. It can be given subjectively as well as objectively. If one listen to the ticking of a clock or the beats of a metronome, it will be noticed that they tend to form units, and that the character of the unit, the sound that is accented, will vary from time to time and, within limits, can be changed at will. Objectively, it is possible to emphasize one unit in the measure, either by increasing the intensity of the note to be accented, or by increasing the length of the note. This is evidenced by a comparison of ancient with modern verse. While the former produced its rhythmic effect by lengthening the syllable, English poetry obtains the same effect by increasing the intensity of the syllable. A similar difference in the way of producing effects can be seen in music of the organ and of the piano. On the organ the intensity is constant, rhythm is obtained by increasing the duration of a tone, while on the piano, accent is given by increasing the intensity of the note. The rhythm is the same in both cases. In fact, men who have played the organ for years often do not notice either the difference in the effect or in the way in which it is produced. Not only may accent be given by changing the character of the note, but also by changing the intervals between the notes. In a measure of three notes of the same intensity and duration, if the first interval be increased, the first note will be accented; if the second interval be increased, the last note will be accented.

The way in which groups are formed in regularly recurrent sensations may also be reduced to certain laws. The more rapid the rate of succession, the greater the number that may be brought into a single unit. In very rapid beats of the metronome, two hundred per minute or so, it is possible to combine as many as eight beats in a single unit. The size of the unit may be varied at will, within limits. When they are sixty or less per minute, it is with difficulty that two may be grouped. In general, Woodrow found that in a series of tones separated by equal intervals in which every other note or every third was more intense, the group would begin with the more intense tone. When intensities were equal but alternate notes were longer, the longer note would start the measure. The grouping and the accent depend upon both objective and subjective factors.

The Theories of Rhythm. — Two theories to explain these various facts of rhythm are at present current. One is that rhythm has a motor origin, that the impulse to beat time is universal, and that any external series that will call out this tendency produces the rhythm. Genetically, it is argued that rhythmic movements are inseparable from bodily activity, that the movements in physical labor came to take on a rhythmic form and this may have been transformed into the dance which in primitive races is frequently derived from the daily work, and that it then was introduced into music and reached its present degree of complexity. The other, an attention theory, develops from the fact that most of the factors that induce accentuation also give rise

to attention. Both intensity and length of stimulus were found among the objective conditions of attention. More striking is the evidence from the effects of the preceding and succeeding interval. A period of expectation is an important factor in arousing attention. Where a note in the rhythmic group has been preceded by an interval, expectation increases regularly during the preliminary wait; and when the stimulus finally makes its appearance, it is more fully attended to and seems more intense than impressions that have been preceded by the shorter interval. Less obvious is the explanation of the effect when a longer interval succeeds the stimulus. This seems to offer opportunity for full attention to the effect of the stimulus after it has stopped, and this is supposed also to increase its apparent intensity. It seems probable, from observation and particularly from the fact that an interval affects the accent of the note that preceded, that the appreciation of the rhythmic unit takes place at the end of the measure. The unit is heard as a whole at the moment it is completed rather than bit by bit as each impression comes to consciousness. The attention theory, then, would hold that rhythm is induced by any circumstance that makes some one or more elements in the series of tones occupy a more important place in consciousness than the others, and that the whole group becomes a unit for attention. While the attention theory has some advantages in explaining why the emphasis comes as it does, it seems probable that a considerable portion of the sensory content of the rhythm is supplied by the motor contractions which may come as a result of the subjective

accentuation. A good case can be made for either theory, and they are not at all contradictory or out of harmony one with the other.

The Perception of Time

Time offers many of the same problems as space. It, too, is a universal characteristic of all our experience, and there has been the same discussion as to whether it has real existence or is merely subjective. As with space, we may ask how short a time can be noticed, and how we appreciate longer intervals. The traditional question, how short a time may be experienced, receives a different answer for each of the senses and combinations of senses. It is much shorter for hearing (.002) than for sight (.044) and may rise to 0.16 second when one stimulus is given by sight, the other by the ear. When one turns to a study of the longer times, it is found that the nature of the estimation of time and even the way time feels varies greatly with the duration of the intervals involved. If one is asked to listen to times of different length, certain are at once pronounced very short, too short to be perceived with comfort, others as too long to be comfortably appreciated. Times under 550σ (σ means thousandths of a second) seem too short, are hurried, and not adequately comprehended. On the other hand, times over about 1800σ seem very long, and it is with difficulty that they can be brought within the span of comprehension. At about four seconds, it is no longer possible to bring the events within a single compass; one reaches the limit of a

single span of time so far as it can be experienced. It should be noted that this is also approximately the length of the primary memory. Within this period events may be held in a single span of memory, and the memory image can be used with the same care and certainty as a sensation. It is by virtue of this fact that it is said to constitute the immediately experienced present.

The Different Ways of Perceiving Time. — The point of division between the hurried and the comfortable time is of interest for another reason. It is found that if one attempts to compare times under 0.6–0.75 second, there is always a tendency to overestimate the first, while similar comparisons of times, greater than this indifference time, lead to the underestimation of the first. This time approximately coincides with the point of division between the times felt as very short and those which seem of moderate duration, and furnishes additional evidence that there is a real difference in the means of estimating times above and below. Some light may be thrown upon the conditions of the perception of time by a study of the factors that influence the comparison of intervals. First, anything that influences expectation plays some part. Thus, if sounds are separated by equal intervals and every other note is more intense, the interval that precedes the more intense sound will seem to be lengthened. This has been explained as due to the surprise induced by the strong tone, which increases the strain ascribed to the preceding interval.

Another factor that influences the appreciation of time

is the way the interval is filled. With short times it is found that filled time seems longer than the same length of time limited by two sounds but otherwise empty. If the time be longer and one be permitted to read during one period and to do nothing during the other, the filled time seems shorter than the empty. The probable explanation of the latter difference is to be found in the fact that the empty time is really filled by noticing strains and other internal sensations, while, during the time occupied in reading, these strains are not present. One forgets one's self and the passage of time in the interesting event. For longer times the filling seems to have a markedly different effect according as the time is regarded as it is being lived through, or as it is viewed in retrospect. While passing, time in which one is occupied fully and during which much of importance is happening seems short, but when viewed in retrospect it seems long. Empty time, on the other hand, seems long in the passing but short in retrospect. During convalescence from a long illness the days drag interminably, but later the period seems inappreciable.

Theories of Time Perception. — Attempts at a theory must take all of these facts into consideration and we must distinguish three ways of appreciating time. First are the very short intervals, those under 600–700σ, below the indifference period. These, it has been suggested, are appreciated in terms of rhythm, since under that limit stimuli may be easily grouped into rhythmic wholes. The intervals are too short to be appreciated for themselves, they cannot be attended to, and so do not reach their full development. From 600 or 700σ

up to about two to four seconds is real time. This is apparently appreciated in terms of internal experiences, expectation processes, and other more definitely kinæsthetic sensations. The length of the time is estimated in terms of the intensity of the strains. Short times give them no chance to become strong, but their strength grows with the longer times. Strains of the muscles that accompany attention, strains of expectation, even strains that come with respiration or with holding the breath, have been asserted to form the basis of the appreciation of the passage of time. The influence of the strength of the limiting stimuli would suggest the importance of the strains of attention and their relaxation in the estimation of time, as would the effect of events that form the content of time in determining the apparent length. When the interval is empty, attention would be more fully attracted to the passage of time, the strains would be more pronounced, and the time seem longer. In the same way with longer intervals when there is nothing to do, the strains of expectation occupy consciousness and time seems long, while, when one is busy, attention is otherwise occupied and there is constant change, constant relaxation, the strains never rise to great intensities, and in consequence one is not impressed with the fact that time is passing.

Times longer than from two to four seconds are apparently not directly experienced in the passing, but are only experienced as past. They fall outside of the present, are constituted for the most part by memories of past events revived in the present. They are estimated in terms of the events that have happened in

them, in terms of their filling. In this they differ altogether from the shorter intervals that may be directly appreciated, and in consequence show the reverse illusions. Thus, times that are filled with interesting events seem long when they are looked back upon, although they seem short in passing; while times in which nothing happens seem short in retrospect, although extremely long in their passage. It is this that explains the seeming decrease in the length of the days and weeks with advancing years. When young, all is interesting from its newness, and is always attended to; as time goes on, nearly everything becomes familiar and receives less and less attention, and so less and less is remembered in retrospect. In general, times depend upon an appreciation of the filling. Very short times are apparently known from rhythm, longer times from the physiological processes, contractions and what not, that give the feeling of expectation and strain; while longer intervals, from two to four seconds, are appreciated in terms of the events that happen in them.

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THE GENERAL LAWS OF PERCEPTION

While space and time may be treated separately, since practically all perceptions imply them and they are considered to have an existence independent of the

objects found in them, certain laws of perception can be illustrated only by the selection of objects in which certain of the common laws may be exemplified. Speaking generally, it may be said that perception is practically never merely a mass of bare sensations. The sensations at most provide a suggestion which is developed in consciousness to make the object as we appreciate it. In optical illusions, certain elements are added, certain others are subtracted from the immediate group of sensations, before we have the final percept. One is not aware of either the additions or the subtractions, much less of the sensations as immediately given before the modifications are made. This same process may be demonstrated to take place in practically every perception before we attain what we call the real object. We are aware only of the final process, the object, but we can be sure from experimental data that this is not the immediate result of sensation, but is the result of a complicated series of mental operations.

Reading. — One of the best means of studying the various laws of perception as they apply to ordinary material is furnished by reading. Here the material is relatively simple and we have fairly full experimental evidence concerning the different phases of the process. First it may be asserted that the word, not the letter, is the unit for reading. This is demonstrated by the experiment on the distribution of attention. As was said in connection with attention, five or six letters is the maximum that can be distinguished on short exposure, but, when combined into words, twenty-five to thirty letters may be read at a single exposure of $\frac{1}{100}$

second. Evidently something must be added to what is seen, or the word must be read as a whole rather than by single letters. There is evidence that both processes go on in some degree. Zeitler and the writer found that the reader was influenced by the general form of the word as determined by the relative positions of high and low letters, the length of the letters, etc. This is indicated again in print by the fact that one is much more likely to make mistakes and to have greater difficulty in making out the words if the upper parts of the words are cut off than if the lower be covered.

On the other hand, the proofreader's illusion indicates that there is a constant tendency to supply letters or parts of letters from memory, to add centrally to peripherally aroused sensations. The writer found that if words were printed with letters omitted, with blurred letters, or with substitutions, and shown for a fifth of a second or less, they were read in a large proportion of the cases as if perfect. The readers would occasionally give reports of the character of the letters, supplied or transformed, which indicated that they belonged in the class of the centrally aroused sensations. The letters that were supplied or replaced were faint or in a peculiar color, or seemed to be less permanent than the others. The likelihood of reading the misprinted word as if it were correctly printed was much increased by calling a word associated with the word to be shown before the exposure. This gave the right attitude or setting for seeing the word intended. That supplementing plays a part in the simplest reading is shown by the large number of misprints that are overlooked, some

even by the most accurate proofreaders. We may assume as a beginning that reading is, in part, a process of seeing and, in part, a process of supplying from memory what we believe to be present. The supplements in this case are not so permanent as are those in optical illusions. The latter persist for a considerable time in spite of all that one can do, and can be destroyed only by a long period of practice, but the proofreader's illusion vanishes when first one looks to make sure that a mistake has not been made.

Reading Pauses. — One might deny that the conditions of ordinary reading, in which all the time that may be desired is given for looking, are similar to those in which the exposure is limited to a period too short to permit eye movements or wandering of attention. Recent studies of the mechanism of reading show, however, that the conditions are not markedly different. In the first place it has been found that, while reading, the eyes do not move steadily along the line with full time for the observation of all details, but make a few brief pauses. Photographs of the eyes as they move along the line show that they stop only from three to six times in a line of ordinary length, and then for but a very short time, approximately a fifth of a second. The number of stops varies greatly with the character of the material to be read. In reading a novel or similar light literature, the number is a minimum and rises to a maximum with difficult material, in proofreading, and for children who are learning to read. One really takes a series of snap shots of a line and pieces it together from those, rather than reading continuously. There is

apparently no reading while the eyes are in motion; they move so rapidly that nothing but a blur of after images is left on the retina, and as this gives no knowledge, we have learned to pay no attention to it.

Reading a Process of Supplementation. — All this leads to the conclusion that ordinary reading is a process of inferring unconsciously from the form of the words and a few letters what the word actually is. This process of inference is really nothing more than associating with the letters seen certain other letters frequently found with them, or of associating whole words with what little of the word is seen. Like all associations, these are under the control of the mental attitude, largely determined by the context and the knowledge that the reader can bring to the reading. The influence of the context can be seen in the different pronunciation and interpretation of a word composed of the same letters in different contexts. 'Lead' has one pronunciation when the subject of the sentence, another when it is the predicate, and one does not think of the one when the other is meant. The difference is altogether in the context, and what has gone before. Still more striking is the difference in pronunciation and interpretation that attaches to the same letters in different languages. *Man* has an entirely different sound and meaning in English and in German, and many other illustrations could be found. Suffice it to say that the sounds or ideas that are aroused depend very definitely upon the context.

In reading it is evident, too, that the process of perceiving or of interpreting is not complete when the

word as such has been seen. The process of translation into ideas follows. Sometimes one sees the words and follows them along with the sound of the spoken word, and then has the ideas associated with them. More frequent in the adult is the immediate translation of the words as seen into images or ideas of some sort. As one reads in the most complete way, pictures or more abstract ideas accompany the reading. The clearer the style, the more immediately do the ideas follow upon the perception of the words and the less prominent are the words, until with a maximum of clearness the words are largely neglected and the meaning alone comes to consciousness. This meaning may take the form of picturing the scenes described, of merely appreciating the abstract meaning, or of something intermediate. In any case, the outlines of black and white that constitute the words start the association processes that lead to the ideas, and these associates are controlled by the wider setting and wider knowledge of the individual at the moment. The process is much like that in ordinary recall except that the stimuli are constantly received from the words. The revival of the earlier experiences is controlled by the laws of association and by the context in a degree that practically amounts in many cases to new construction.

Understanding Spoken Language. — A similar process occurs in listening to another's speech. One does not appreciate how small is the proportion of a conversation that is heard distinctly until one attempts to follow a foreign language. Then it is seen that what must be perfectly clear to a native as a vehicle for ideas is really

only a series of grunts and hisses with an occasional word clearly enunciated. Suggested by these, the words or the ideas are supplied through association. Bagley has shown that there is a process of filling out the imperfections of sounds similar to the interpretation of letters in reading. The laws of supplementing are practically the same in the two cases. Something is given by the ear, this suggests words as one would speak them one's self or as they would look on the printed page. This is all that is really appreciated, and even when one listens for the words, the imperfections are not noticed. When one hears a strange accent, the different deviations from the sounds one is accustomed to are overlooked, the man is assigned to his region of the country, and then no more attention is paid to the speech characteristics, unless one be interested in phonetics or have some other purpose in hearing the sounds, and then the sense of what is being said is very likely to be lost. Artificial languages gradually take on the same character. The separate elements become united into word units, and then take on meaning as do words themselves. This comes out particularly clearly in learning the telegraphic language. There at first the sounds are heard as small groups and put together painstakingly and slowly into letters, but gradually words are heard as wholes and the meaning is suggested by a few words and omissions filled in as in ordinary speech. Supplementing follows the same laws as in reading or listening.

If one may extend and generalize the laws of perception in reading and listening, it may be said that perception is primarily a process of arousing old experiences

through association. These associations are controlled by both the subjective and the objective factors. Some few sensations always serve as the incentive to the perception process, but they serve as the incentive only. By them associations are aroused and, in the arousal of the associations, all the experiences that have had any bearing on the process play a part. Some of the associations are determined through mere frequency of appearance with the original stimulus; more depends upon the attitude in which one is at the moment of looking or listening, and upon the inherent probabilities of the situation. That one is not more often misled is due to the fact that objective situations repeat themselves so frequently, quite as frequently as do ideas. It is safe on the whole to assume that what we take as the sign of an old situation really accompanies that situation, for in the vast majority of cases the remainder of the elements are actually present. In practice it would take more trouble to stop to investigate than to take the chance and be wrong the few times that the new does not correspond to the old. It is striking, however, that in this case alone one does not distinguish between real sensations and the recalled images. Centrally and peripherally aroused sensations are combined in almost all perceptions, but one never can tell where the sensations stop and mental supplements begin. One seems as real as the other.

The Influence of the Type in Perception. — One other general law of perception may be an outcome of those already mentioned but probably contains in addition elements that connect perception with the reason-

ing processes, — this is the tendency to replace a particular phase or aspect of an object by what has proved to be its more general or universal form. Usually one sees things as the previous experience convinces one they must be, rather than as they appear at the particular moment. Thus, one usually does not notice shadows as shadows, although they may play a considerable part in the interpretation of the form of the surface on which they fall. Similarly, one does not notice how indistinct are objects in the field of vision a little distance from the fixation point. What is seen is at once translated into an object of perfect form with full detail and distinctness, and all else serves as a mere background. Still more striking is the correction of the size of various objects mentioned above. The standard size varies for the different objects. No matter how small or how large the image may be under a given set of circumstances, it is increased or decreased to a standard size. The image itself is never seen, the fact that it has been changed in its size also is not noticed; the corrected standardized impression at once replaces the original image. This standard we regard as the real object.

Similar tendencies to replace mere sensation groups by concepts or by standardized objects may be seen anywhere. The neglect of after-images, of contrast colors, the overlooking of imperfections in the media of the eye that can be seen clearly when one looks for them in a lamp flame, overlooking the retinal blood vessels in the visual field, — all of these omissions are quite as apparent as is the addition of qualities or characteristics not given in sensation. Equally striking are the

changes in the forms of objects seen in perspective. As any article of furniture is looked at, the square corners are either increased to oblique angles or reduced to acute angles, according to the side from which one looks. A hundred students looking from different directions at the lecturer's reading desk will each receive a different impression, different in shape as well as in size, but the object is the same for all. The perception is changed in being seen, or a standard object is made to replace the various images, so that the final result is the same for each observer. This process of replacing the crude image by a standard object, an object that has been developed by all of the individual's experiences, that has been gradually corrected by being seen under different conditions, by being handled, and even by making similar objects or seeing them made, is practically universal. It is the developed standard object that always comes to consciousness, just as it is the corrected standard space that is always used as the basis of reference. To anticipate the discussion of a later problem it may be said that we perceive concepts rather than sensations. As concepts that have developed in this way, we have not merely objects, but space and time and similar abstractions which are in part components of the objects, in part to be regarded as independent.

CHAPTER X

MEMORY

Memory is a topic that bulks very large in the discussion of daily life. It may be defined as the awareness of the fact that a certain event has been experienced in the past. In the complete form it may be defined as the recurrence of a group of experiences with knowledge of when and where they were experienced before. Memory is related to centrally excited sensation in very much the same way that perception is related to sensations. It is a group of centrally excited sensations accepted as representing some earlier seen object or previous event, as perception represents an object actually present. Unlike sensations, whether of peripheral or central origin, both are concrete mental processes, not mere abstractions. All of the actual materials of memory and the laws that are involved in the recurrence of ideas have been discussed in connection with centrally aroused sensations, save only in so far as these involve meaning and recognition, — the fact that the processes recalled represent things and are referred to the correct period in the past.

While the fundamentals of memory have been discussed, there is much of more particular application that remains to be considered — questions as to how the association processes may be used to the best advantage in the accumulation and application of knowledge. We

may conveniently divide memory into four part processes, —learning, retention, recall, and recognition. Learning is no more than the formation of association, and retention their persistence; but while both have been treated in general, we must consider here a large number of special rules and laws developed through experiment that throw new light on the nature and use of memory. If learning has to do with the formation of connections, recall depends upon the degree in which the associations may become effective. To have the associations is not identical with being able to use them. We may weave together the results obtained from experiments on the first three processes, before we consider recognition which involves certain relatively new principles.

Experimental Methods. — Careful experiments on memory were first made by Ebbinghaus in the eighties of the last century. To avoid the variation in degree of familiarity and interest that might attach to words or any other material that has meaning, nonsense syllables were selected as the material to be learned. These were built up systematically of all possible combinations of consonants and vowels, two consonants with a vowel between. All were excluded that chanced to make sense. Series were selected by lot from the mass of syllables. Ebbinghaus wrote his series upon cards and then learned them by shuffling the cards. Most later workers have arranged the syllables upon some sort of revolving drum that exposes them at regular intervals and for definite times. They are said through regularly as they are exposed, until they can be repeated once or twice without mistake. Ebbinghaus measured the amount of effort

in learning by the time required, but most later writers have chosen the number of repetitions as the measure. Two methods have been used to test the accuracy of the learning or the amount of retention. The first, known as the method of relearning, was used by Ebbinghaus. It consisted in relearning the syllables, and assumed that the difference between the time required for learning and for relearning was a measure of the amount retained. This also measured the value of the method of learning used. In a second method, developed by Müller and Schumann and extensively used since, the syllables are learned in pairs and the amount retained is measured by showing the first of each pair and determining the number of times the second syllable may be supplied. The percentage of correct answers indicates the amount retained. In many experiments, the time required for speaking the second syllable is measured. This serves as an indication of the strength of the association for individual pairs. The shorter the interval required, the stronger is the association. Each of these methods has given valuable results. They frequently supplement each other. The first measures primarily the learning of the series as wholes, while the second permits a study of the learning of individual pairs and of parts of the series as well.

The Laws of Learning

Effect of Individual Repetitions. — One of the first preliminaries to the application of the method was to determine the accuracy of the method itself. One of the most important of these was to discover the effects produced

by each repetition when a number of repetitions are made of the same series. One might expect that later repetitions would be less effective than the earlier. Ebbinghaus tested this by repeating a series of syllables eight times and then finding the time required to relearn after twenty-four hours. He then repeated another series sixteen times and again relearned after the same interval. These experiments were repeated up to sixty-four repetitions of a series. Within these limits the saving after twenty-four hours was directly proportional to the number of original repetitions. The last repetitions were no less effective than the first as measured by the amount retained. The diagram shows that the results, when plotted, lie almost in a straight line. Each repetition resulted in a saving of about twelve seconds in the time required for relearning. This experiment brings out the fact that learning is never absolutely complete or perfect. Perfect learning at the moment will show defects in a few hours or days, and the time and accuracy of retention may be increased by repetitions much beyond the number required for the first perfect repetition. Each repetition will have the same effect as any other in the recall of the next day or of the next week.

Relation between Length of Series and Number of Repetitions. — One of the more striking facts in connection with learning is the great increase in the number of repetitions required for the longer series as compared with the shorter. It is found that an adult can remember from six to eight syllables or eleven to thirteen numbers with a single repetition, while Ebbinghaus found that it

took 13 repetitions to learn a series of 10 syllables, 16.6 for 12, 30 for 16, 44 for 24, 55 for 36. As the number of syllables in a series increases, the number of repetitions required for learning it increases much more rapidly than in proportion to the increase in the number of syllables. The most striking increase is seen when the series is just longer than can be learned with one repetition. The

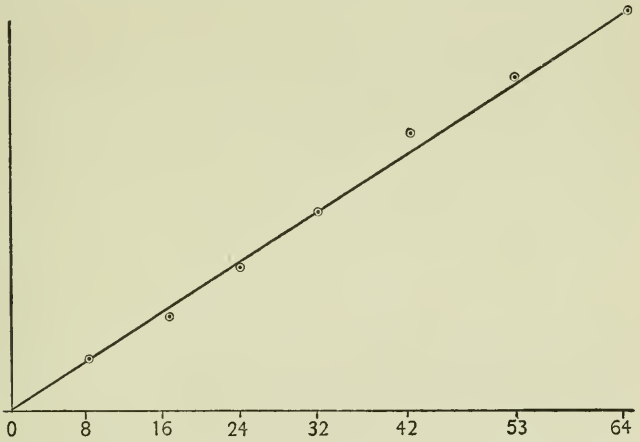

FIG. 87. — Shows the increase in amount retained after twenty-four hours with the number of repetitions. The number of repetitions is plotted on the horizontal, the saving in seconds on the vertical axis.

number of syllables that may be taken in at a single reading has been called the memory span, or primary memory. This varies very markedly with age, with training, and with the individual. It may be much increased by training at any age. According to Meumann, children from seven to nine can usually retain no more than two or three nonsense syllables, while the practised adult retains seven or eight.

Effects of Grouping. — Learning a series not only makes associations between the contiguous syllables of the series, but knits the whole group together by associations formed between all of the syllables, however widely they may be separated. Ebbinghaus demonstrated this by first learning series and then making up new series that should consist in part of the syllables of the primary ones. Thus, he would select syllables that had been separated by one syllable, and found that the new series could be learned more easily than new syllables. He repeated the experiment, using syllables that had been separated by two, three, etc., syllables up to those that had been separated in the original learning by as many as eight. He found in each case that a saving could be shown as compared with entirely new series. The results prove that, in a series, associations are formed between the remote as well as the contiguous elements. He also showed that associations are formed in both directions, backward as well as forward. Relearning a series backward saves about one-third of the time saved in relearning forward. It has also been shown that there is some connection formed between the syllable and its position in the series. Syllables that are relearned in the same absolute position in a series are relearned more easily than when they take a new position. If the syllable is the third or the seventh in the series and is kept in third or seventh place, relearning is easier than if it is shifted to second or fifth place in the new series. All of these bonds of connection serve to make the series a unit.

Effects of Rhythm. — Anything that serves to unite the syllables into minor units is of advantage in aiding learn-

ing. One of the means employed most frequently is rhythm. In repeating a series, the syllables are practically always combined in rhythmic units and given an accent. Learning in the natural rhythm is much easier than in a forced rhythm or without rhythm. The natural rhythm varies with the individual and probably also with the race, but whatever the rhythm used, some benefit is derived from it. The rhythmic unit also serves as a subordinate group within which associations are much stronger than between contiguous syllables of different groups. Müller demonstrated this by first learning series in trochaic rhythm and then forming from the syllables two sets of new syllables. In one of these, the syllables were relearned in the same measures as in the original series; in the others, the syllables were contiguous but had belonged to different measures. The former showed a saving on relearning equivalent to five repetitions; the latter, no appreciable saving. This strong association within the group holds, not merely for the grouping in rhythmic units, but for any grouping. In learning nonsense syllables, there is practically no association formed between the first syllable of one series and the last of the preceding. In common life little connection is established between conversations on different subjects with different persons, even if one immediately succeeds the other. On the other hand, where material to be remembered is broken up into smaller groups of a larger series, members of these groups are more closely associated for themselves, and learning the groups aids in learning the total series. This formation of subordinate groups is of great practical importance, and we shall have

occasion to refer to it in connection with the development of meaning.

Learning by Whole and Part. — Of the more practical laws for learning, one of the most important is that it is much easier to learn any selection if it is repeated as a whole instead of by parts. This applies to nonsense material under strict experimental conditions, but is of more interest in connection with learning selections that have meaning, poems, etc. The investigations were first carried out by Miss Steffens under the direction of Professor Müller. They consisted in comparing the time required for poems when learned as most people incline to learn them, a line or a couplet at a time, with the time required when they are read through from beginning to end each time. The results indicate that in practically every case learning as a whole is more economical than learning in parts. The saving amounted to about ten per cent in Miss Steffens' experiments and held for children as well as for adults. Later investigations by Meumann showed that two stanzas required thirty-three repetitions by the part method, and only fourteen for the whole procedure. It should be said that unless some method of keeping the repetitions at a uniform rate be employed, the learner tends to lose interest and to repeat more slowly than he will if he is permitted to learn by parts. In some experiments it has been shown that this loss in rate almost compensated for the gain in repetitions. With practice, this may be overcome. That the principle is correct has been shown repeatedly, since not only does learning require fewer repetitions, but the material learned as a whole is much better retained than material

learned in parts. There is also a fairly wide limit of application, as the whole method was found more economical by Pyle for selections that required as much as fifty minutes to read through.

The reasons for the greater efficiency are threefold. 1. They save much of the time ordinarily wasted in needless repetitions. In the part method, the first part of the selection is repeated more times than necessary through going back to connect the later learned with the earlier. There are several times as many repetitions of the first as of the later. 2. Needless associations are made each time the reader goes back from the end of a line to its beginning. These take time and also may interfere with the formation of the correct associates. 3. As was said above, the connection of a word with its position in the selection is of some advantage in learning, and the whole method always retains the absolute position of each word. Meumann and his pupils have shown that certain intermediate methods may improve on the strict method. Thus, it is frequently an advantage, after a number of repetitions of the whole, to repeat several times the parts of the selection that offer special difficulties, and to learn them without making unnecessary repetitions of the easier portions. One can also obtain some of the advantages of the part method by making pauses at certain places, and then going on from that place after a few seconds. These pauses seem to attract particular attention to the words preceding and succeeding them, without the disadvantage of forming useless connections. In general, it is recommended that one read through the selection to be learned a few times as a whole, then, as

fatigue comes on, introduce the pauses, and, when it becomes evident that certain parts are offering special difficulties, make an extra number of repetitions of those parts until they are learned, then add a few repetitions of the whole to weld all together.

Distributed Repetitions More Effective. — Another law that is equally well established, quite as important in practice, and even more interesting, is the so-called law of divided repetitions. Briefly, this is that the more the repetitions are distributed over different days, the fewer the repetitions required and the more thoroughly the material is mastered. It was first carefully investigated by Jost. He tried learning nonsense syllables with twenty-four repetitions at one time, then similar series with eight repetitions per day for three days, then four for six days, and finally two a day for twelve days. It was found when they were tested by the method of paired associates twenty-four hours after the last repetition, that the fewer the repetitions each day, the greater was the amount retained. Ebbinghaus had earlier compared greater numbers of repetitions. On one occasion he read a series of twelve syllables 68 times and found that twenty-four hours later he needed seven repetitions to relearn. Then he repeated another of the same length, $17\frac{1}{2}$, 12, and $8\frac{1}{2}$ times, a total of 38, and found but five repetitions were needed for relearning twenty-four hours later. Still later Miss Perkins continued the extension of distributions, comparing accumulated repetitions of eight a day for two days, with four and two and one repetition per day, every other day, every third, and every fourth day. The results were tested after fourteen days

and proved even more striking than those of the earlier tests which were made after twenty-four hours. Eight repetitions a day gave only from 9 to 17 per cent correct responses, and the larger number was obtained when three days were permitted to elapse between each series of eight repetitions. Four readings a day gave from 25 to 41 per cent, with larger values for the wider distribution of repetitions; two a day gave from 45 to 78 per cent, while a single repetition every day gave 79 per cent; a single repetition every other day, 72 per cent; every third day, 82 per cent, and every fourth day, 68 per cent. It would seem, then, that one repetition every second or third day gives a maximum value for learning.

This law has been tested a number of times on children and adults, and even on the learning of animals, and always with the same results. Ulrich[1] found that white rats could learn a maze with fewest repetitions if they were given one trial each third day. It holds also for sense material as well as for nonsense syllables. The explanation of the advantage of divided repetitions was suggested by some of the experiments of Jost. He found that, when he compared the number of repetitions required to completely develop two sets of associates of equal strength but of different ages, the older required fewer repetitions than the younger. His method was to learn one series of syllables twenty-four hours before and then to make a few repetitions of another series a few hours before the test. The amount retained was tested by the method of paired associates. When three times as many

[1] Watson, Behavior, pp. 228 ff.

correct associates could be given from the newer series, it required almost the same number of repetitions to bring each to the point where it could be said through without mistake. When the number of correct associates that could be given was approximately the same for both series, the older series could be fully learned much more easily than the more recent. His theory is that the associations continue to grow strong, to 'set,' for some time, perhaps for two or three days after they are first formed. That associations tend to increase in strength for a few days is known as 'Jost's Law.' This unearned increment that comes from the setting process makes it much easier to bring them back to full effectiveness some time after the learning, than if no time is permitted to elapse after the repetitions are first made. It is possible to connect this setting process with the continued activity, perseveration tendency, that constitutes the primary memory or immediate retention. This setting is one more expression of the inertia of the nervous system.

Several important practical deductions may readily be drawn from this law. Obviously, it is a close corollary of the preceding law, since, if one is to read through each time, only short selections could be learned in any one day. Coupled with the advantage from divided repetitions, it gains full force, since, if the selection be not learned at the first sitting, it is an advantage to wait a day or two before proceeding to complete the learning. Again the bearing upon the familiar topic of cramming is quite evident. What is repeated often at periods considerable distances apart is learned thoroughly, while

accumulated repetitions in a brief period produce slight effect and one that quickly disappears. This is more certain from the fact that divided repetitions leave much more persistent effects than accumulated. In general, the more the repetitions are divided up to one every third day, the more permanent will be the learning.

Rate of Repetitions. — Other factors that affect learning are the rate at which the material is read and the degree of activity or the degree of attention given it. The rate of repetition has been several times investigated with slightly different results. Ebbinghaus first asserted that the more rapid the rate, the quicker the learning. Ogden modified this by showing that learning was quickest when reading was at the fastest rate possible without too much effort. Part of this difference lay in the fact that Ebbinghaus used the time alone as a measure of effectiveness; Ogden employed both time and the number of repetitions. Meumann, as a result of experience gained from many investigations, concludes that the best rate varies with the individual, the material to be learned, and the familiarity of the learner with the material. It is best to read relatively slowly at first when the subject matter is being understood, and more rapidly later, up to the point where the effort begins to distract.

Active Repetitions More Effective than Passive. — The effects of the attention of the reader have been investigated numerically only in one respect, the advantages of passive reading as compared with active repetition. Witasek made experiments to determine the best

combination of reading with attempts to repeat. He found that the most satisfactory result was obtained when he read five times and then repeated fifteen times from memory. It is evident that attempting to repeat from memory requires more effort and will hold attention much more than passive reading. It should be said, however, that repeating material that has lost its freshness in an abstracted state, practically without attention, will give rise to learning in a much shorter time than one would think, although it is of course not so effective as repetition with full attention. Still another factor that plays an important part in learning is the intention to recall. Meumann and others found a saving of 50 per cent or more if series were repeated with the expectation of being tested on them later, as compared with similar series that were learned without knowing that the learning was to be tested.

Associative Inhibition. — An important factor in preventing learning is the presence of other earlier formed associations with the syllables to be learned. Müller and Schumann found that, if two associates are made with the same syllable, they interfere with each other, and the second will be learned with greater difficulty. They demonstrated this by learning in different series syllables *a*, *d*, *g*, etc., first with *b*, *e*, *h*, etc., and then in another connection; *a* with *c*, *d* with *f*, *g* with *j*, etc. It was found that it took considerably longer to learn the series of syllables when other syllables had already been connected with them than when learned for the first time. In the experiments, the syllables to be relearned were interspersed irregularly, so that the association with the

old positions and with syllables, that were near but not contiguous in the first connections, should not aid in the relearning. In practical life this means that when one thing has been learned with another, it will require a longer time to learn it with a second than if it had not been learned with the first. If a mistake has been made, it will take longer to correct it than to have learned correctly in the first place. But where several things are to be learned in the same connection, it is found that inhibition ceases to be effective if the first is thoroughly learned before the second is begun. In fact, in that case there is apparently some saving, since the familiarity with the old saves some work in learning the new. This interference of earlier formed associates with the formation of new ones is known as the associative inhibition.

Retention and Forgetting

The Rate of Forgetting. — The investigations of the retention of associations bear largely upon the rate of the disappearance of associations with time. There is a general tendency toward the unlocking of associations that begins at the moment of reading or a few moments later, and goes on indefinitely. Two long studies have been made of this topic, one by Ebbinghaus, the other by Radossawljewitsch. Their results may be compared in the table on the following page.[1]

[1] Ebbinghaus considered learning complete when he could repeat once; Radossawljewitsch, when he could repeat twice without mistake.

Length of Interval	Per Cent Forgotten	
	E	R
5 min.		2.5
20 min.	41.8	11.4
1 hr.	55.8	29.3
8 hr. 45 min.	64.2	
8 hr.		52.6
1 day	66.3	32.2
2 days	72.2	39.1
6 days	74.6	50.7
30 days	78.9	79.8
120 days		97.2

The main difference is to be seen in the fact that Ebbinghaus found a larger percentage forgotten in the shorter periods. Both indicate a relatively rapid forgetting at first, and a relatively slow rate in the longer intervals. It should be remembered that nonsense syllables were used and that these are forgotten much more quickly than sense material. The comparative rapidity of forgetting during the first few days suggested to Müller that there might very likely be two factors to take into consideration; first, the tendency to perseveration or the memory after-image which diminishes very rapidly and may be regarded as disappearing in the first two days or so, and the associative tendency, which in accordance with Jost's law is to be conceived as increasing in strength for two days or more and then decreasing in strength very slowly. For most purposes the increase in the strength of the associative tendency is masked in the total curve by the rapid decrease of the perseverative tendency, but later the decrease in

the strength of association is represented by the curve of forgetting (Fig. 88).

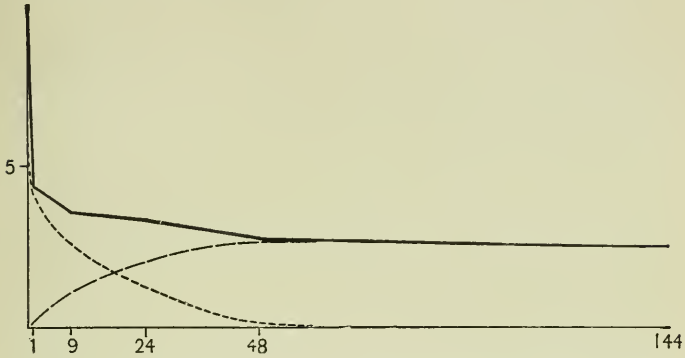

FIG. 88. — Analysis of the curve of forgetting to show possible coöperation of perseveration and association. The full line shows the course of forgetting after Ebbinghaus, the dotted line the conjectured decrease in the primary memory (perseveration) and the dashes the initial increase in the strength of association due to perseveration.

Is Forgetting ever Complete? — It is evident from these studies that associations persist when there is little immediate awareness of them, when one cannot even bring them back by an associate closely connected with them; when they can be detected only from the fact that they may be relearned more easily than if they had not previously been learned. This fact has given rise to much discussion as to whether anything is ever forgotten. The discussion arose originally from the fact that occasionally long-forgotten events from a remote past are recalled. Coleridge cites the case of a girl, a servant in the house of a pastor who was accustomed to walk up and down a passageway near the kitchen where she was employed, rēciting passages from Greek, Latin, and He-

brew authors. Some years later in a delirium of fever she was heard to recite strange words that convinced her attendants that she was possessed of a devil. The physician wrote them down and traced them to works in the possession of the old pastor, now some years dead. If the case is to be accepted, memories that never were consciously developed and which should have been forgotten if they ever had been developed may still be lying dormant in the nervous system. Numerous other cases may be cited of the return of experiences long forgotten, usually in case of disease, under hypnosis, or in similar abnormal conditions. These cannot be taken to prove the thesis for which they are adduced, but they may serve to reënforce the statement that experiences leave their effect for some time after they can no longer be recalled through associations of ordinary strength. Not improbably the nervous system never altogether loses some trace of them. This fact is of more importance in explaining recognition, the control of belief, and similar processes, in understanding which we must appeal to the effect of experiences not definitely conscious at the moment, than as a contribution to the understanding of retention and recall. Memories constantly grow weaker at a rate that depends upon their meaning and interest, and gradually, if not refreshed, reach the stage at which they cannot be revived.

Recall

Recall, as was seen in the earlier chapter, is always through association under the control of the wider purpose of the moment and of other less conscious factors that

constitute the mental attitude or context. To recall any old event it is necessary to have some idea which is in some way connected with that event or has some element in common with it. If we assume the possession of a definite memory with a large number of connections, some one of the connections must become conscious before the memory itself will make its appearance. Usually the desire to remember is, either itself an associate of the memory desired, or they are both connected with a common idea. Thus, when one is asked a question in an examination, the question has been connected with the answer and serves or should serve to recall it. The course of the association is determined by the setting, the context of the question is supplied by the subject in which the examination is held. In practical life the occasion for the recall is a need for the bit of knowledge. A face presents itself and one knows that the name will be needed when it becomes necessary to make an introduction, or one is reading of the size of a ship in metres and wonders how long it is in feet and must recall the table of equivalents. In each case there is always something that makes it desirable to know the thing to be recalled, and this has also been associated with the fact. Not all associates of an idea are actually recalled. The reason for this is usually that the right context is lacking. One may read of the length of the ship in comparison with other ships whose lengths are also given in metres, and as relative size is all that is necessary, the thought of the equivalent does not occur to one. The mental attitude or need of the moment always plays a predominant part.

Reproductive Inhibition. — Interesting, if relatively unusual, are the instances in which one has occasion for a fact, is sure that it is known, perhaps well known, but in which one cannot recall it. One may be asked the name of a famous painter, find to one's astonishment that it cannot be recalled, torture one's memory for it as one may. Frequently after the occasion for it has passed, it will come back without the least difficulty, often when thinking of something entirely different. Phenomena of this sort seem to fall under the head of reproductive inhibition that was established by Müller and Schumann and confirmed by Shepard and Vogelsonger. It was found that, when two syllables were learned at different times in connection with one single first syllable, there was not merely an obstruction to the formation of the second association through the earlier formation of the first, but also an inhibition of the recall of both when the common first member of each pair was shown. The time required for the recall of either is much increased while the percentage of times that either will be recalled correctly is correspondingly decreased. It seems probable that something like this happens in the moments of blocked recall of familiar facts. The associations must be present as is shown by the later recall, but apparently too many associates strive for entrance, and each, through some neural interference, blocks the way of the other. It should be added that there is some evidence, obtained by Bair[1] in his experiments on learning typewriting, that when a series of associates has been fully learned — when

[1] J. H. Bair, The Practice Curve, Psychological Rev. Mon. Supplements, No. 19.

one keyboard of the typewriter has been thoroughly mastered — another can be learned in less time and there is no interference between them on recall. Were this not true, there would always be interference. A blocking of recall would be much more frequent than we find it, since practically every bit of knowledge has many associates that might be recalled. The effect of the purpose or attitude must play a large part in the prevention of inhibition. When the context favors one associate much more than another, the way is cleared for it and all others are kept from interfering. Interference comes only when the associations are not fully formed, are relatively weak, or no strong purpose is dominant.

If learning and retention depend upon the formation of associations and the degree in which they persist, recall is also through the connections that are formed in learning. It, too, is largely a mechanical process, dependent upon the relative strength of the associations, guided only by the context and the purpose of the moment. The laws that have been given are statements of the conditions under which the associations may be formed with greatest strength and in the shortest time, together with an enumeration of the factors that influence retention and the course of the forgetting, and the laws of recall. All this is of value in practice, since the laws hold not only under experimental conditions and for nonsense syllables, but also for sense material under conditions of ordinary learning. But in addition to these laws that apply to the raw materials of memory, the fact that memory ordinarily deals with things as real introduces the elements of meaning and logical

interconnection, two factors which are important in determining the ease of learning and recall and the use to be made of ideas. The most important influence of meaning, in fact what first gives meaning to groups of centrally excited sensations, is recognition. By recognition we mean that the idea has been accepted and given a place in the experience of the individual. It is this in large measure that transforms the raw materials into ideas, into objects and events that have a real relation to the past life of the individual and to his knowledge.

Recognition

Recognition is a process that plays a very large part in our mental life, and has close relations with reasoning as well as with perception and memory. We recognize objects as well as memories, and neither an object nor a memory can be used if it is not recognized, or understood, and understanding is closely related to recognition, if not a form of recognition. By recognition is meant the reference of an event or object to some earlier time and place. It is a tagging by which we assign the experience a place in our earlier life. The process of recognition has a number of degrees and several forms. What may be regarded as complete recognition is an assurance of where the object was seen before, and a recall of all the circumstances of that earlier experience. This is called definite as opposed to indefinite recognition. In the latter, one is aware that the thing is familiar but can assign no definite place to it. Many faces are familiar which recall no name and cannot even be referred to a

specific time or place. This indefinite recognition is ordinarily due to slight familiarity. At the other extreme, things that are very familiar also are recognized but referred to no definite place. Here the recognition is taken for granted. This happens with the furniture of a well-known room, with intimate friends, and with events that are frequently recalled. It is an implicit as opposed to an explicit recognition. The objects are treated as if known, arouse a feeling that is different from that aroused by strange objects, but are seldom referred to earlier times or even named.

Another reduction from complete recognition is seen in what may be called cognition, assigning a new event to a class even if it is seen for the first time. This applies to all memories and to all objects save those that are absolutely without connection with our past, if any such present themselves to the educated civilized man. One only occasionally recognizes or cares to recognize a dog, unless it be his own, but is still able to place it, to give its breed. In a strange place, most things are cognized, are assigned to a class, although none may be recognized. Still another distinction must be drawn with reference to the way in which recognition takes place. In certain instances one can see how the recognition goes on. A hauntingly familiar memory makes its appearance, but it has no connections and can be given no place. Gradually as one broods over it, other things are called up by it. Then suddenly an associate, itself familiar, is added to it, and recognition is complete. This may be called mediate as opposed to the immediate recognition, which is much more usual. As will be seen, each of these types

of recognition depends upon the same laws and has the same explanation; they are different forms of the same process.

Influence of Types on Recognition. — Experimental study of recognition shows that it takes a different course for material that can be given a definite connection with something that is itself familiar as compared with material that has no such associates. This difference can be made to explain apparent contradictions in experimental results obtained by two of the early experimenters in this field,—Wolfe and Lehmann. Both sought to determine the influence of the lapse of time upon the accuracy of recognition. Wolfe worked with tones which could be made to differ by as little as four vibrations, and had a number of tones at his command, so that they could not be readily referred to a class or given a distinguishing name. He found that capacity to recognize diminished with the passage of time, at almost the same rate as the ability to recall. His curve showed the same form as Ebbinghaus' curve of forgetting; recognition fell off rapidly at first and much more slowly later. Lehmann used gray papers of different shades. At first he used five shades. These his subjects at once arranged in a series and gave a definite name to each. His results showed almost no tendency to diminution of accuracy with the passage of time. At first the judgments increased slightly in accuracy and then declined slightly, but there was no approach to the logarithmic curve obtained by Ebbinghaus. When Lehmann introduced nine shades, these were given numbers from one to nine, and the curve retained the same form. Later investigations

by Angell and Hayward and by Hayden under approximately the same conditions have given results similar to Lehmann's. The difference in the results obtained by Wolfe and the others may be attributed to the degree in which the material makes possible the association of a word or other familiar symbol. Where no such symbol may attach, recognition is difficult, and ability to recognize vanishes very quickly. When the symbol may be applied, recognition is immediate and persists for some time with no appreciable diminution. Back of the assignment of the name or number is the development of a definite image or notion of the different impressions to be recognized that shall make it stand out for itself, that shall make it a fixed standard.

This difference between the results obtained by Wolfe and those obtained by the others is similar to the difference between results with nonsense and sense material. A number of recent experiments by Hollingworth, Miss Mulhall, Strong, and others showed the same difference in ease of recognition between material that has and that which has not meaning. They found in the first place that recognition was much more certain and persisted longer than ordinary recall. It was from two to three times as accurate as recall when advertisements, pictures, words, or other sense material was used. But with nonsense syllables, recognition had very little if any advantage over recall. If we apply this to our other problem, it is evident that recognition of meaningful material has a very great advantage over recognition of nonsense material. In the one case the shades of gray could be immediately connected with words that had either a

definite meaning acquired long before these experiments were begun, or that could be quickly developed for the few shades used. One association alone needed to be formed in order to assure recognition in each experiment. Recognition itself required no more than a decision whether the shade offered did or did not correspond to the standard required. In Wolfe's experiments, no standards were present at the beginning and none could be readily developed because of the great number of tones used, and the slight differences in pitch that were available. Here one dealt with bare association processes formed during the experiments between sensations, neither of which had a meaning of its own. All the preparation for recognition must be made during the experiment, while in the experiments with meaningful material, most of the preparation was completed before the experiments were begun. Meaning, then, contributes much to the ease and persistence of recognition.

The Association Theory of Recognition. — Theories of recognition are very numerous and in some degree conflicting. One has been already indicated, the placing of the unknown through association with the known. This can be traced empirically very frequently. One hears the title of a book, it sounds familiar but can be given no place. Gradually, ideas cluster about it until it is placed as a novel by so and so read on the boat two years ago, or it may be it is remembered to be the book that was recommended by Jones but which has not been read. Similarly with objects. This bit of crystal at first seems to be absolutely unknown, then a background grows up about it, you remember where it came from;

that supplies the name and the purpose for which you obtained it, and the whole recognition is complete. The association theory assumes that all recognition is of this type, and that in the cases in which the recognition is indefinite the associates are present and have their effect, although they are overlooked or do not come to full consciousness. They nevertheless provide the mark of familiarity, give a color to consciousness that is accepted as a warrant for the belief that the idea or object has been experienced before. Another theory with many adherents is that the feeling of familiarity comes from slight movements awakened by the stimulus or image. This is approximately the same theory as the other, except that the processes aroused are motor rather than sensory. The idea arouses some habitual movement, slight or more intense, and this constitutes the basis of the assurance that the object has been seen before. The movements themselves are not recognized, but because of their arousal the familiarity attaches at once to the object. The best instance of this is to be found in the feeling of ' at homeness ' that comes with the use of an old tool or instrument when one comes back to it after a period, as compared with the feeling of a strange one, even if it is of the same pattern. The habits that have been developed in its use are suited to it, and the pleasant feeling of familiarity results.

Recognition an Immediate Quality. — Another group of theories starts with the assumption that recognition is an immediate experience that cannot be analyzed or explained, but must either be accepted as a given fact or be speculated about in general terms. The more defi-

nite of these theories asserts that recognition comes because of the pleasure that attaches to the familiar experience as compared with the unpleasantness or neutral quality of the unknown. The pleasure is explained as the result of an instinct. The known is pleasant, since one always makes an immediate response to it. If harmful, one can avoid it immediately; if beneficial, it is pleasant in and of itself. The objection to the theory is based primarily on fact. Not all cases of recognition are pleasant, certainly not all pleasant things are familiar. Another theory in this group asserts that familiarity is an immediate conscious experience, even more primary than either sensation or association. This theory has a chance if all others fail. The same objections hold to it as to nativism in space. It gives up the problem without attempting an explanation.

The evidence so far accumulated favors the association theory in some form. Recognition of the indirect type can be traced to associations. In the direct or immediate type, things that have many associates are readily recognized, while nonsense material, that is material without associates, is recognized with difficulty, is recognized no more easily than it is remembered. Recognition is aided also by two of the factors that aid association. Meyer showed that recognition of nonsense syllables was more accurate when a syllable with which it had previously been associated was shown, just before the syllable to be recognized was presented. It has been shown, too, that recognition is quicker and more accurate if the individual is in the proper attitude toward the object to be recognized just before it is shown. Just as in

everyday life, if one meet an old acquaintance, one is very much more likely to recognize him if one has been thinking about the place where he was known, than if he appears without any preparation. These four facts together indicate that association and recognition are very closely related. Recognition always comes when associates are aroused, and where associates are not overtly present, experiments indicate that conditions which favor the formation of associates or recall by association also favor recognition.

Meaning and Recognition. — In any statement of the association theory of recognition, it must be recognized that the associates must be themselves familiar or the process will not be complete. Sometimes several links are necessary before a familiar associate presents itself. This familiarity that attaches to these added associates and also to the objects recognized immediately is itself due to associates. The difference between the mediate and the immediate is another expression of the difference between the two sorts of recognition that distinguished the methods used by Wolfe and by Lehmann. One must get back to some established type, to something that has been used so frequently and recalled so often that it has become firmly established and thoroughly familiar. These are accepted at once and without question. They are the types that we found necessary to explain perception, and are also the concepts that play an essential part in reasoning. Probably these fixed points of reference for our knowledge are also established and receive recognition through the numerous associates that they tend to arouse but which do not become explicit. Your own

name, to take an extreme case, is established more firmly than the name of another because of the number of times it has been associated with yourself and with other experiences. Events that serve as landmarks in all memory become such from the number of associates that have been made with them many times through their frequent recall in different connections. When an event, that is at first unplaced, can be attached to one of these firmly established incidents, it at once takes on something of its familiarity, in the same way that assignment of the name was all that was necessary in Lehmann's experiments to constitute recognition of the shade. Probably the feeling of familiarity is due in these very frequently repeated objects and events to partially open association paths that give recognition without any definite recall of the associated events. In case the object is familiar but cannot be definitely placed, it is probable that there are also partially open association paths, but they do not lead to the meaningful object or to the fixed landmark. The feeling is present with nothing to fix the experience. Similarly, in certain cases in which the recognition is false, when one sees an individual who seems familiar but on speaking finds that he is not an acquaintance, it is probable that something in the person suggests another or calls up associates that are misplaced. Here the associates give the feeling without even warrant in fact. In short, partially open association paths give the feeling of familiarity when recognition is not complete and even when the recognition is not objectively true. In the constant recognition of everyday objects, familiarity is the rule, strangeness the exception. In consequence,

the fact of recognition, as well as how it takes place, is seldom noticed. Only the unknown attracts attention.

Recognition and Cognition. — Recognition is largely aided by the types that were found to play so large a part in perception, and also by meaning, a process fundamental to thinking of all types. The part played by the type and by meaning may be seen more clearly in the more generalized form, cognition. Here objects are referred to classes rather than to particular times or places. It is more frequent than recognition. We are constantly referring all objects that come under our notice to a class. Natural objects are named, tools related to their uses, people are assigned to different races or classes when they are not acquaintances. This process of cognition differs from recognition only in that there is no reference to the earlier experience of the individual, no awareness that the thing has ever before been seen. Except for determining ownership of objects and for our relations with people, it is seldom that we need to do more than cognize. Cognition differs from recognition only in that the reference is to some class only, some type of objects, with no reference to personal knowledge. The process involves the same factors, there is always a general notion as the point of attachment, but this has a more or less marked series of associations that irradiate from it to give appreciation of its use, or of its special characteristics. In almost every respect it is like the type or concept that we saw to be aroused in perception, and to constitute what we accept as the real object. Cognition is a reference of the particular object or memory image to a similar typical object or class. Memory is like percep-

tion in that it deals with real objects or concepts, rather than with mere centrally excited sensations.

Meaning in Learning. — Meaning is not only a factor in making recognition possible but is also an important factor in all learning. The meaning that the material to be learned has for the individual determines in very large degree how quickly it may be learned and how long it shall be retained. The difference in the amount of time required for learning and the degree of retention between sense and nonsense material is very striking. This may be seen both in primary memory and in learning long series. Ebbinghaus found that school children could give only five of seven nonsense syllables, while of a sentence of 38 words containing seventeen separate ideas, they could remember fifteen of the ideas. For himself he found that with the same number of repetitions he could remember eight or nine times as much of simple poetry as of nonsense syllables. Meumann obtained slightly smaller values, 7–9 nonsense syllables, 13 words or numbers, 20 words of a poem, and 24 of philosophical prose.

Meaning not only aids in learning but also assures a greater persistence of the material that is learned. The material learned is much less readily forgotten. Ebbinghaus demonstrated the fact for rote memory of verse. In some of his earlier experiments he used a translation of Byron's "Don Juan." After twenty-two years, he found that he could detect a saving of 7 per cent in the time required for relearning stanzas as compared with learning new stanzas. After seventeen years there was a saving of 20 per cent in relearning stanzas which had originally

been learned on four successive days. This is to be compared with a saving of 20 per cent for nonsense syllables at the end of thirty days. The retention of ideas is still more complete. General principles, or even interesting events, are frequently recalled after the greater part of a lifetime. Here, however, there is usually repetition or recall in the intervening years.

Meaning Due to Grouping and to Reference to Systems of Experiences. — Two reasons may be found for the greater ease of learning meaningful material. One is that to gain meaning the different partial experiences must be grouped about a single centre, must be combined into units, and these units are then remembered practically as single elements. In some recent investigations of a lightning calculator, Dr. Rückle, G. E. Müller found that an essential element of his ability to make calculations very quickly lay in the capacity for remembering figures, and that this in turn was due to an ability to unite the figures into small groups. Rückle could retain and repeat in any order forty-nine digits. He saw them arranged in seven columns of seven digits each. The seven series seemed to count for him as seven single units. A second element in acquiring meaning, well illustrated by this same investigation, is the attachment of the thing to be remembered to elements of experience already firmly fixed, — an interpretation in the light of old knowledge. Rückle related many of the numbers that he could remember to combinations of numbers with which he was already familiar. Thus he could remember 451,697, since it was made up of the multiples of two prime numbers: $451 = 11 \times 41$, $697 = 17 \times 41$. Six

hundred and twenty-four was easy, since it is the square of 25 minus 1.[1] With a large acquaintance with numbers, learning new ones was relatively easy. All material that has meaning has these two qualities. It is combined into relatively small groups. These groups are used over and over again until they constitute practically a unit and they are learned in different connections until firmly established and then can be recalled by many other experiences. When anything has meaning, it is already connected with something that is a part of the fundamental intellectual equipment of the individual. In this, to have meaning and to be recognized or cognized are approximately identical. Thus, recognition we saw to consist in attaching to the object or idea that is to be recognized some mark in itself familiar. The permanency of recognition, then, becomes the permanency of the older acquirement. In learning material that has meaning, the same factor is even more prominent. When the meaning of anything is understood, it is by that very fact united to the already familiar, becomes an instance under a general law or a general class, and that gives it in large degree the permanence of the general law. The meaningful material, by virtue of the fact of having meaning, will then be sure to belong to a larger group and so become easier to learn, and will also be connected with something that is already known and which permits the new to be understood. These two characteristics alone would go far toward explaining the advantage for learning of sense material.

The importance of meaning can be seen to still better advantage in the type of learning most frequently prac-

[1] Zeitschrift f. Psychologie, Ergänzungsbd. 5, pp. 215 ff.

tised in adult life, learning the substance without the words. In this there must be some connection with a wider knowledge, or nothing can be retained. Almost anything that is understood can be retained for a little time, and to understand is, in essence, to connect the new with the previously organized knowledge. The degree of retention depends in part upon frequency of repetition of the ideas, but much more upon the number of different ways in which the new is linked to the old, and thus to the completeness with which it is understood. While the process of understanding is more important on the whole than the formation of discrete associations, both must be present in some degree. Meaning has a basis in association, as has been pointed out, and, on the other hand, frequent repetition, even of nonsense syllables, tends to give them some meaning, however slight. For practical purposes they are usually opposed. In rote learning only the associates between the elements are considered; in sense material the connections with the more general knowledge is emphasized. When one is learning by rote, the meaning of the material may be lost sight of; in sense learning, the words may be altogether neglected. Either can be trained at the expense of the other. Individual differences in the use of one or the other are matters of training, and it is possible to acquire the ability to use either at will.

Individual Differences in Memory. — Not merely is there a difference in the degree to which rote and sense memory may be used, but there are differences in the capacity of learning in general and in the aptitude for learning different kinds of material. One of the most discussed

is the difference between quick and slow learners. Ebbinghaus asserts that there is a law of compensation in learning in that, if one learns slowly, one also forgets slowly. The instances chosen prove only that there is a greater percentage of saving for the slower learners, but the number of repetitions required for relearning is least with the quick learner, and not so very much greater for those who learned more slowly in the beginning. Later experiments indicate that the quick learner is more effective in every respect. At the best, then, the slow learner has an advantage only in the percentage remembered, not in the amount that may be recalled by associates or in the time required for relearning. In several of the cases given, a quick learner would learn and relearn twenty-four hours later in fewer repetitions than the slow learner required for the first learning.

Dependence upon Age. — The dependence of memory upon age is fairly well made out. Measured either by the memory span, the quickness of learning, or the immediate retention, memory increases gradually to thirteen, then improves very rapidly to sixteen, and then more slowly to a maximum at twenty-two to twenty-five, then apparently persists approximately unimpaired throughout life, or at least until the onset of senile decay. Meumann grants that children may retain material once learned rather better than adults, a fact which accounts for the large percentage of our memories that come from early childhood, but both immediate memory and ease of learning are greatest after maturity has been attained. Another factor that may be regarded at any moment as an individual difference, although it may depend upon

habit, is the tendency to remember meanings or to remember by rote. This accounts for part of the apparent advantage of children. They are accustomed to learn by rote, and for that reason do it relatively better than do adults, who are at once lost in the meaning and find difficulty in forcing themselves to attend to the words. This can of course be cultivated either way, and adults who have cultivated rote learning have an advantage in this also.

Dependence upon Types of Imagery. — Still another more truly individual characteristic is to be found in the dependence of memory upon sensorial type. An individual of a visual type is probably more successful in remembering words, colors, landscapes, and similar material; an individual of the auditory type, in musical memories of all sorts and for the order of material that is learned. Which type is absolutely the best is not known, since investigations have not extended to a sufficiently large number of individuals. Meumann asserts that the visual memory is best for the retention of the elements, but that the motor-auditory obtains a more accurate grasp of the whole. In the work of the arithmetical prodigies or lightning calculators, differences in memory type play a considerable part in determining the character of their feats. Two that have been studied, Diamandi and Dr. Rückle, were visual in type, and one, Inaudi, was auditory-motor. The motor type did not lend itself to the reversal of operations, but with simpler processes was much quicker than the visual. On the whole the motor memory was quicker as far as it went, but much less flexible than the visual memory. When space factors

entered, the visual far outstripped the motor-auditory. These are but illustrations of differences in capacity that depend upon the memory type. Much remains to be done before we can state all the differences.

Economy of Memory. — If one be asked how to learn to the best advantage, or how to improve one's memory or capacity for remembering, the best answer is to apply the rules given under the different heads of this chapter. If material is to be learned by rote, it is essential that there should be a large number of repetitions. In any case the repetitions should be divided over as many days as possible and should also be made by the whole method, and not part by part or bit by bit. The units should be grouped into wholes as far as possible, since this grouping reduces the work that must be done in learning. Above all, however, wherever the material to be learned has any meaning, it is essential to understand it. Material understood is more than half learned. In the process of understanding, it is well to approach the material from as many different points of view as possible. The greater the number of points of attachment, the more thorough is the understanding, and also the greater the number of connections by which to arouse the memory in recall. Where matter is to be learned by rote as well as in substance, it is well to make two or three repetitions to understand the material, and then to proceed to commit to memory by repetition. It is essential also to attempt to repeat unaided as soon as possible. Usually after four or five repetitions, a free recall should be begun and frequent tests made of the parts that are least well recalled.

Memory Systems. — Numerous attempts have been made since classical time to develop methods of aiding memory. Latin orators made use of the device of picturing their orations upon the walls of different rooms of a house, one part on each wall of a room, and larger units in the same room. As they proceeded, they would picture themselves as walking through the house and reading their various headings from the walls. A more modern form of mnemonics, but one that goes back several centuries, consists in forming series of links, based upon chance associates between any two things that are to be recalled together. Thus one may remember that Δ is the Greek letter delta by the series: triangle, pyramid, Nile, Delta. Or it may be remembered that Denver is the capital of Colorado through the lingo, Colorado, dodo, bird, dense air, Denver. Similar connections are made by these systems between any two facts that are to be connected. Obviously any scheme of this kind will, in the long run, prove more harmful than helpful, as it involves making four or five associates where only one is needed, and the others are likely to develop inhibitions as well as waste time. It is much better to trust to forming the associations directly, and better still, if connections are needed, to base them upon some fundamental general principle. The system of the sciences is from one point of view merely a big mnemonic system, a means of bringing a large number of isolated facts into connection with each other in some logical way. To make use of that as a means of remembering is to follow a plan that has been developed by the best minds of all times, rather than some chance scheme that has been hit upon by a charlatan.

Transfer of Training.—A question of practical as well as theoretical interest is whether exercises in learning may be said to train memory, whether training in learning one sort of material or under one set of conditions is transferred to learning some other material or under another set of conditions. All experiments in learning under experimental conditions show important improvement with practice. There is also some improvement when one practises on nonsense syllables and tests by the capacity to learn sense material or by any form of rote learning. It has sometimes been held that memory was something that could be trained in and of itself like a muscle. Practically all modern evidence favors the view that the improvement is really in the methods that are used in learning. One becomes accustomed to attending under the peculiar conditions of the laboratory; one forms, consciously or unconsciously, good habits of study, learns to read with the intention of remembering, and these factors may be carried over to any other material with advantage. From what we know, this is the only sense in which memory can be improved in any general fundamental way, and this is sufficient to account for the improvement actually demonstrated. Another form of improvement can be noticed in connection with sense material, a form that comes without effort and is a necessary part of all learning. This is the increase in ability to understand which develops with increased knowledge. As knowledge accumulates and is well ordered, more points of reference develop and each of these serves as a peg upon which new facts may be hung. Just as Dr. Rückle's new numbers could be referred to numbers

known as the squares and cubes of small numbers, and could be remembered in terms of those, so a new fact that can be given a place in the system of knowledge, as an instance of a familiar principle, is readily remembered. This system of knowledge grows with learning, and as each addition to it is preparation for new acquirement, all learning may be said in this sense to train the memory.

Imagination. — Imagination is a word that is constantly heard in popular speech and has been much used by psychologists. Unfortunately, however, the usage has been so varied that it is difficult to select one that can be said to be general. It has connections with both memory and reasoning. We speak of constructive imagination as approximately the same as reasoning, and of reproductive imagination as if it had about the same function as memory. Many recent writers use it to indicate the primary functions discussed in connection with centrally excited sensations. This goes back to the primary meaning of the term as a process of forming images. So far as our needs are concerned, imagination may be used to designate those mental processes in which the resulting idea is not referred to a definite period in the past as in memory, and is not regarded as a true construction and guide to conduct as are the results of reasoning. The laws of revival of the old experiences which hold for memory hold also for imagination, but the product is not recognized; on the contrary, it is held to refer to no time or place in the past, to represent no actual event. As compared with reasoning, its results are not accepted as true absolutely, but are assured to be possible only under certain conditions not themselves accepted as

likely. In other words, it is assigned but a limited and conditional truth. In any case, imagination differs from memory only in the attitude taken toward the final product, is practically identical with it in the conditions that determine its origin. To anticipate, it may be said that it differs from reason also only in the attitude that is taken towards the outcome. One believes when one reasons; one need not believe when one imagines.

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CHAPTER XI

REASONING

MENTAL operations are not restricted to receiving impressions from the outside world and to recalling experiences received at some earlier time. Quite as important, in many respects much more important, are the operations in which experience already accumulated is used in the anticipation of future experiences, in understanding and organizing earlier experiences, and in the development of new constructions, mental and physical. Were these constructive activities to be eliminated, much that is peculiarly human, all that makes progress possible, would disappear. Reasoning in its wider applications covers all of the constructive processes. It organizes the past in preparation for the future, it makes mental constructions that may later be developed through action into real productions. But while the end of reasoning is construction, it builds upon the materials that have been provided by perception and memory. Many of its fundamental laws are similar to those that have already been developed. Most, if not all, reasoning is concerned with problem solving; reasoning proper is restricted to solving problems in thought alone, although the problem once solved may and usually does prepare for real construction. The results attained in thought lead directly to

and control action. We may for convenience distinguish two types of problems, — those that have reference only to the purely mental constructions, to the mere understanding of the world, and those which go beyond in preparing the way for action. This distinction is of more importance in theory than in practice, since both sets of problems are solved in the same way. The distinction comes only after the problem is solved, in the use that is made of the solution. In the one, we are content with a mere understanding of the problem; in the other, we prepare for the attainment of some practical end.

Reasoning Involves Meaning. — One factor common to all reasoning, as it is to so many of the processes already discussed, is meaning. We must attempt to bring together the evidence that has gradually been developing through the earlier chapters as to what meaning is. Perhaps the greatest obstacle to determining what meaning is arises from the fact that we are usually not directly conscious of anything other than the meaning. We are always concerned with the thing meant and take that for granted with no attempt to determine how the object is represented in consciousness or how what is in consciousness can represent the thing. At present two main theories are in the field. The one, suggested by Külpe and the so-called Würzburg school and by Woodworth, asserts that all meaning comes immediately and cannot be explained, that it is an immediate fact of consciousness, perhaps the most important fact of consciousness, and that is all that can be said of it. They would assert that in addition to the images and sensations in consciousness, there is another sort of mental function,

the meaning, and that all reasoning and practically all other mental operations are carried out in terms of it. The meaning needs no images even to carry the reference. When one thinks, one rises to a new realm of pure thought that is not definitely related to the ordinary state of consciousness. The second theory finds the explanation of meaning in the associates that have been formed with the image in question and which, through their arousal, or partial arousal, give rise to the meaning.

Theories of Meaning. — In discussing the theories, the first thing to be kept in mind is that the assumption of meaning as fundamental is not a proof. We must take very much the same attitude towards it as towards the nativistic theory of space. It is something to be accepted if no other explanation can be found. Of itself it is no explanation, merely a denial that any of the earlier suggestions hold. The imageless characteristic of meaning must be kept in mind as we run through the results of earlier discussions to find analogies for meaning. In this, as in the representative character, the simpler processes offer many points of similarity. Meaning offers the same problem as the local sign in space perception. There we found that the touch was always referred outward to the skin, meant a point on the skin, but no one could say from examination of the mental state what it was that made it mean that point. This is one of the simplest cases of imageless reference, but few people have been content to stop with recognition of that fact. As we have seen, many attempts have been made to discover what might be involved in that reference. This fact of imageless reference of percep-

tions outward characterizes all space perception. The appreciation of the distance of an object by the eyes or ears is a similar instance of reference that can be given no explanation from immediate observation. One is aware that the object is at a certain distance but has no direct means of determining how one knows. Here experimental analysis has been more successful than in the localization of stimulations on the surface of the body. As we have seen, the reference outward depends upon the presence of strains from eye muscles, intrinsic and extrinsic, upon double images, in themselves not noticed, which have become associated with different distances. It is characteristic of this reference also that the occasion for thinking of a particular distance is never noticed; one thinks of the distance itself without any known intermediary. The objects are thought of as at a distance from us, and we think of nothing but the objects as outside; we have no notion that the impression is inside and projected outward on the basis of some sensory content, plus associations.

The same general rule holds of all perceptions. One is not aware of the letters or the words in reading; the meaning alone comes to consciousness. The sensory content at the basis of the appreciation of the meaning is not noticed; it is shown to have an existence only by experiments. Even in the optical illusions the same process can be shown to exist and is more striking, as the meaning that is supplied is out of harmony with the facts, and thus can in no way be referred to an immediate appreciation of external reality. One looks at the Müller-Lyer figure, *e.g.*, and sees nothing more than that one line is

longer than another. The intermediate steps are not appreciated, and again can be inferred only from various tests and analogies. In each of the forms of perception that have been discussed, — and many others could be mentioned, — we find a typical case of what has been called imageless reference. The explanation of all is found in the presence of certain sensory elements which have had associations with other experiences that are altogether different, and in each case the notion that has been associated with the experience is what comes to consciousness. The images that represent it in consciousness are not themselves noticed, are unconscious, if one may indulge in paradoxes.

Meaning Related to Recognition. — Another analogy with meaning is offered by recognition. A name presents itself as one is reading and at once it is noticed that it seems familiar, one is prepared to accept it. This offers one of the best instances of mental state or process that has full and immediate meaning. If one takes an instance of delayed or obstructed recognition, it has been shown in the last chapter that one places the name by the gradual addition of associates. If the name is of an author, recognition comes when some of his works are recalled in connection with him; in cases of personal familiarity, the face or a picture of the face may be added before recognition is complete. Recognition is practically always through associations. Recognition contains all of the elements of meaning. If the recognition is not particular but the object is a new member of a familiar class, to cognize, to have the object take on meaning, is practically identical with a reference to that general

class. If recognition consists in the addition of associates which may or may not be fully conscious, it is certainly possible and altogether probable that meaning is a generalized form of recognition, and should also be due to the addition of associates. As the associates in recognition are not conscious as discrete processes in most cases, so in meaning the associates are not ordinarily fully developed and may be entirely unconscious.

The relation between recognition and meaningful material in memory has already been indicated in the last chapter. Recognition and meaning follow approximately the same laws. One remembers about the same proportion of material that can be recognized as of material that has meaning. Recall and recognition of nonsense material require approximately the same time. Only in material that has its associates already fully fixed is it possible to recognize more easily than to recall. Meaningful material in memory is such as may be referred to more general heads, to more general notions, or to other things that are in themselves familiar. If we bring together the relations between meaning and the other forms of reference that we have dealt with in the more concrete processes, we find that, as in perception and recognition, the thing meant is usually all that is in consciousness at any time, that neither the sensory elements which make the reference nor the associates that may be said to constitute or at least to furnish a basis for it are definitely in mind with it. On the other hand, in most cases it can be shown indirectly that associates really give rise to the meaning, and in others it seems probable from analogy that associates in the physiological sense play the

important part in giving meaning, in making the reference. This theory assumes that there is a consciousness of meaning that comes with the opening of association paths, even when the associates do not fully come to light. The same assumption is necessary if we are to hold that recognition may come as a result of associates when no definite associates are apparent and if we are to explain reference of a touch to a certain portion of the skin or of a visual percept to a definite distance, when one is not at all aware of the sensory elements that lead to, nor of the associates that constitute, the reference.

We may grant, then, with the exponents of the pure thought theory, that, as a conscious content, meaning differs from what are called the static elements, but we would insist, on the other hand, that it is an outgrowth or accompaniment of the opening of cerebral paths, on the same level as those that lead to recall. Secondly, we may assume with them that the quality, state, or function is not one that appears seldom and only in connection with reasoning, but rather it is fundamental to all concrete mental processes, low as well as high. The states that have not meaning must be regarded as the exceptions to be explained rather than the reverse. One should add that in all states from percepts to abstract thought, the meaning alone may dominate consciousness and the element that might be said to carry the meaning may have no existence or be lost in its meaning, as the local sign is lost in the reference to a point on the skin. The only exception we take to the other school is that they regard meaning as immediately given, while we believe it is derived. The meaning, then, may be defined

as the fact of reference from some state or process outward, a fact of reference that may be an unanalyzable state of consciousness, but which probably depends upon the presence of partially opened association paths.

The Concept as Representative. — Equally important for reasoning and recognized much earlier than the meaning is the concept. The concept is usually defined as an abstract idea that contains elements of many particulars. For the logician, 'man' in the abstract means all men, either as representative of the class, or as containing all the qualities of humanity as a whole. Water as a concept might be represented by a chemical formula, by its physical qualities, or it might be regarded as a type of all the different particular kinds of water. There is always in the concept something of the representative, and something, too, of the organized, harmonized, and corrected experience. In so far as the concept is representative, it is closely related to the meaning, it may be regarded as the mental process that carries the meaning, and becomes a concept because of its associates, — because of the concrete single and simple experiences that it represents. Thus, I may think the word ' man ' and intend it to stand for all men in a certain relation. Because of its meanings, its associates, the word does duty for all of the particulars; it becomes unnecessary to think of each separately and in detail. Regarded from this standpoint, the concept as a mental state may have any form. It is very frequently a word, sometimes it is a single object that stands for many others. Thus a model deposited in the patent office represents legally all machines that may be constructed on a given plan,

no matter of what size or of what materials they may be made. A drawing of a geometrical figure may be representative of all figures of any size and of many shapes. The various single objects that it represents may be said to be the meaning of the figure; they are the associates that it does or may call out, and what is affirmed of it holds of each of the others also. It is possible to make assertions in this way of the concept because each of the elements that it represents, each of the partially awakened associates, would prevent any assertion that would not hold as well of each of the particulars. It is in terms of concepts of this sort that one may reason in abstract terms; although the concept itself as a mental content is particular, it represents an abstraction or a number of concrete objects.

Concept as Type. — In another sense, however, the concept may be the thing that is meant. It may be what is referred to by the mental content. This second sort of concept is what is represented by the concept in the sense used above. In this sense all knowledge is made up of concepts, and these are related to the particulars as the fully unified to the rough materials. One may picture the system of knowledge as made up of various elements that have been fitted together to constitute a consistent whole. These elements are for the most part not given immediately in sensation, but are the results of various refinements, of various ways of working over the raw materials, until some order is brought into the originally inchoate mass. We have seen the process at work even in perception. As was pointed out there on several occasions, what is perceived is not merely a

mass of sensations, nor is it a single sensation that suggests some other single sensation or group of sensations; rather is it a type, an organized product of many experiences which have finally given rise to a construct consistent with all of our different related experiences. This it is that is thought when a single stimulus presents itself. Thus, to repeat our simple instance, we see the top of a table as square, not because it is square on the retina, nor because we have seen it more frequently under conditions that make it appear square than when distorted by perspective, — probably it never has been seen undistorted, — but because all that we know about the table top harmonizes with the assumption that it is square. When tested or measured it proves to be square; a similar surface must be made with right angles, it fits into square corners. It is believed to be square because that assumption fits in with all of our other experiences.

Development of Concepts. — It is by this method that most of the notions of external objects develop. Position is a notion that cannot be referred to any single experience. Depth also cannot be said to be merely the sensation of the motion necessary to reach the object, but is rather a concept or type developed through many tests and accepted because it harmonizes or orders many different experiences. Space in general is a similar type. If we turn from perception to less objective things, the same principle may be applied. The development of the number concept can be followed among the different primitive nations. In northern Borneo, the natives still have no developed notion of number apart from objects. When counting they use the fingers and toes,

and when the number rises above twenty, another man is called and the objects are checked against his fingers and toes. The remnants of this counting can easily be traced in the decimal system and in the score. In this instance the concept carries with it more of the original sensory material from which it develops than do space and position, but in the course of time the separation from the concrete is complete, and now number carries with it practically no implication of fingers and toes except for the use of a few words, such as digits.

Knowledge a System of Concepts. — Leaving aside for the moment the question of how the concepts develop, it is evident that organized knowledge consists in its entirety of a system of concepts. When anything can be referred to a concept, we place it, we can use it, we understand. On the other hand, when it is possible to develop a notion or concept that will organize a group of facts, we accept the concept as true and use it until some new facts appear that are out of harmony with it, when that concept is given up and another substituted for it. Just as in the perception of space, the concept or type is assumed to be real and all else is adjusted to it, so in science or philosophy or in everyday life the concepts are accepted as the reals, other experiences are merely appearance. The systems of concepts are by no means consistent with each other, but must be consistent within themselves. Thus, if one consider the experience of perceiving the table from the standpoint of the concepts of the different sciences, we would be told, on the one hand, that it was nothing but a mass of atoms of hydrogen and carbon and oxygen in different arrangements with a few

odd elements thrown in; that its peculiar character depended upon the way the atoms were grouped in the molecules. For the chemist it is this and nothing more. For the physicist the picture changes. Atoms go into the background and forces come to the front. Attraction for the earth keeps it in place and gives it weight. It is seen by the vibrations in the ether that it reflects, and its color is determined by the rays that it absorbs and reflects. If one happens to be talking to a physicist of the latest school, electricity replaces ether and its vibrations. In any case, explanation is in terms of a system of concepts, however the concepts may differ. The physiologist finds his explanation of the experience in the nervous structure of the eye, in photo-chemical processes in the rods and cones, in the excitations and responses of the neurones. For the psychologist, again, we have a group of sensations of strain, of light and shade, of images. These are the types or concepts to which experience is referred as the psychologist attempts to understand it. In short, our simple experience has been dissolved in a great many different ways, no one of which leaves anything of the original experience, and yet without this dissolution into concepts, it could not be understood.

Without the concepts all would be confusion. This is clear from a study of the early languages and the lower forms of human thought. It is asserted that among the lower south African tribes there is no notion of direction in the absolute sense. The individual gropes his way from place to place by memory of each landmark along the way, and has no idea in which direction he is

going. He cannot keep his bearing even with reference to the rising or the setting sun. How confused the notion of the world must be can easily be appreciated. Similarly, where numbers are restricted to a score, where length can be measured only in paces, or in days' journeys, and other concepts are equally faulty or altogether lacking, all thought must be decidedly vague and uncertain. Even the use of purely personal concepts of force, as in the explanation of the winds and other natural phenomena by spirits, and the general anthropomorphic explanation of events and causes, means that little progress can be made in the accurate understanding or use of natural forces. Adequacy of the concepts means adequacy of understanding, and that in turn means successful action and application of means to ends. What experience would be like without concepts one cannot appreciate. It would be of course a hopeless confusion, like waking from a bad dream into an entirely new environment. Nothing would be clear, nothing would be definite. For all intents and purposes, without concepts there would be no consciousness. Adequate concepts go hand in hand with possibility of adequate thought.

The problem of the origin of concepts in this sense of the word has been one of the persistent problems of philosophy. We find the general theories divide themselves like the theories of space into those which assume concepts and regard them as determining the course of development of knowledge, and those which would develop the concepts themselves from and through experience. Plato, for example, has in his ideas a system of concepts that are innate, the representatives in man of the eternal

verities, through which all experience obtains what truth it may have. On the other hand, we have more empirical theories that would derive them from the experience of the individual, and in the case of the more fully developed concepts, as worked over and tested by the race on the basis of individual suggestions. This is in the large the suggestion that was made with reference to the types in perception. They may be in part or at times derived by the accumulation of particular experiences that have been consolidated or modified by use. In large part and in many cases, however, they seem to result from hitting by chance upon some construction that harmonizes with the experiences. When a construction is found that meets this test, it is accepted. Certain it is that concepts are modified with the passage of time and the growth of knowledge, and it is just as certain that a concept is seldom the direct product of the action of the senses. In the formation of laws, experimental science shows a tendency to consolidate particular observations into generalizations and also a tendency for trial and error to play a part in the formation of concepts. For our purposes it is more important to insist that our knowledge, as used in thought and developed through perception, becomes largely a system of concepts, of types, and that these serve to explain the concrete and in many cases in themselves to constitute the concrete. Without them knowledge would be no knowledge but a mere mass of confusion.

Concept as Representative Idea and as Type. — Two forms of the concept may then be distinguished. The first is a definite mental state that means a number

of particulars or a number of general qualities of any sort. This takes the form of a word, a typical group of sensations, or may reduce to nothing or very nearly nothing but the meaning, the reference itself. The second form is an organized idea, a type that has been proved by tests to satisfy many experiences, and in consequence is accepted as real. It is this concept that is usually meant. It is what we accept as the external object of common sense, it is the fundamental structure or force or principle of explanation in natural science, or in psychology. Such concepts are our sensations, our associations and percepts, — in fact, all of the notions that we have been developing in the attempt to explain mental life. In many cases these types, too, are not absolutely clearly pictured but are represented in consciousness in some schematic fashion. At other times, as in perception, the types constitute the clearest and most definite structures of consciousness. They are consciousness, and all else is subordinated to them. In every case they are all that we are really conscious of at the moment, whether they be meant merely or whether they be actually reproduced in all their clearness.

The Stages of Active Reasoning. — At each point in active reasoning, use is made both of meaning and of the concept. Most of reasoning consists in bringing order into experience and in justifying suggestions for new advances. In both, reference to the established system of knowledge, to concepts and generally accepted laws, plays a prominent part. Practically all reasoning operations deal with real things or their symbols, involve meaning only. The active processes in reasoning may

be divided for convenience into four. These are the incentive to reason which is usually forced upon us by some difficulty, some opposition to progress either in action or in thought, or something which makes a continued inaction undesirable. The second is to analyze the difficulty, to understand it. This constitutes judgment. After the difficulty is understood, means must be discovered for removing it, and this we know as inference. Finally, the conclusion must be tested, must be shown to be correct, and this constitutes proof. These states must be considered one by one. Reasoning as a whole must have a positive stimulus. The problem is always forced upon the individual by some inadequacy of old habits or of old thoughts, by something that goes wrong in the ordinary routine. Where habit and routine suffice, one never reasons. Necessity is the mother of all thought, as of all invention. The problem usually presents itself by the man's being thwarted in his mental or physical progress. On the mental side some fact presents itself that will not fit into the theories already developed. The number of species of beetles challenged Darwin to discover a reason, the flight of birds and insects challenged Langley and Wright to find some mechanical means of imitating them. Each suggestion that ideas may be realized starts the discoverer on a quest for the means. Granted the problem, the next stage is an analysis of the problem into its elements or conditions to obtain a better understanding of what is to be done.

Judgment. — This process of analysis consists of a reference of the parts of the problem to its peculiar concept or class. The process of reference to a type is

known as the judgment. In the solution of any mechanical problem, the building of a bridge, *e.g.*, it is necessary to reduce the various strains to their components, to measure the intensity of each, before means can be found for resisting them. In designing a building, the engineer goes beyond the ordinary rule of thumb, determines how much pressure the building will exert downward, how much will be expended in lateral thrusts, what the wind pressure is likely to be at a maximum, and only when these various components of the problem have been determined is he ready to decide what material must be used and how the structural elements may be distributed. The process of analysis is essential at every step in advance of action. It consists in referring the new to old and familiar experiences so far as the new offers points of similarity with the old. This is the first point at which the background of older experience aids in the new construction, in progress of any sort. Only in so far as the problem can be reduced to its parts and the parts referred to established concepts can it be said to be understood, and only then is it possible to go ahead safely. To act before the situation is understood is to act in the dark and ineffectively.

The process of judging consists of the reference of a new experience or an entering sensation to an old concept. In one sense it is simply the perception process over again. A stimulus presents itself and, before it is really conscious, it is referred to some old type; it is given a meaning, and thereby becomes fully conscious. The process called judgment by the formal logician is approximately the same, although more explicit and definitely represented

in words. Thus 'man is mortal' is a judgment; *man* is the subject, *mortal* is the predicate. The subject represents the presented, the thing given to be understood, and the predicate the concept by which it is explained. The process of judging brings the new under some head or category already established.

Judgments of Relation and Evaluation. — In addition to this use of the term judgment to designate the reference of the unknown to some definite concept, it is used also to indicate comparison and evaluation, uses more closely related to the popular. One is said to judge when one compares two lines and also when one estimates the value of anything, assigns the money value to a horse or other article of merchandise, or estimates the guilt of the prisoner at the bar. In each case there is approximately the same process. One has a scale of values that has been developed in the course of many experiences. The present article is given its place in the list on the basis of various similarities to things judged before, some explicit, some implicit and indefinite. A similar process is present in judicial decisions. A particular crime is referred to the general scale and the punishment affixed in accordance with the scale. Comparisons are also references to types, but to typical relations not to typical things. Relations are as much concepts as are space or time. Greater and less are typical relations developed to make it possible to understand certain phases of experience. To measure it was necessary to develop the concepts of relation in space and time and energy, and measurement is the foundation of civilized life. When one asserts that a line is longer than another, one merely looks

from one to the other in immediate succession, and the concept greater or less suggests itself, the pair is referred to one class or the other immediately. The process is just like the recognition of a new object or any similar classification. The judgment in general is a reference of a new thing or situation to a familiar head, the reference of a particular or unknown to a general type, a reference that prepares one to treat it adequately. In our particular practical case, it is a process of analyzing the elements of the problem in preparation for its solution.

Inference. — Granted that the problem has been stated and understood, the next process is to discover a solution. This process roughly corresponds to the inference of the formal logician. The only difference lies in the fact that formal logic is inclined to combine the real discovery of the solution with the proof that it is the solution. Finding the solution, inference in our sense, consists in a process or series of processes of association. If, when the judgment is complete, the new situation can be reduced to familiar elements, the solution is practically completed; the older solutions may suffice or may be combined in the attainment of the new desired end. In these cases association under the suitable more general controls may be all that is necessary. In many other instances the process cannot be reduced to laws, although probably each suggestion is controlled by definite laws of association. One can be sure only that there will be many attempts of different sorts before the solution is finally reached. Inference has more points of resemblance to an animal struggling to get out of a box or to the man with a new puzzle than to the ordinary notion of the ac-

tion of a calculating human being. In these cases the process is one of repeatedly trying, with a readiness to reject all but the right solution.

Inference a Process of Trial and Error. — When one is trying to solve a puzzle, first one movement is made and then another, until finally by chance success is attained. In thinking out the solution for a problem very much the same process is used except that the trials are only in thought. One thinks of some way of changing the thing or the situation, and when one believes that this will not work when fully developed, tries another. If that is rejected, then a third is presented; the process continues until one is hit upon that promises to work. With difficult problems the process of trying solutions and rejecting them may last for hours, and of course in important inventions the trials may continue for years before the right solution is hit upon. Frequently, an approximation to the solution will be reached and then the process of transforming or perfecting will go on by the same method for an equally long time before what can be considered a complete solution will be hit upon. In the case of actual inventions or the solution of actual problems, the final satisfaction may come almost by accident, if one can distinguish between accident and intention in such an operation. Almost the only direction that can be given for the attainment of the end is to keep trying. Persistence is the only virtue, the rest is very largely a matter of chance. There are certain minds in which ideas spring readily, that seem fertile in suggestions of all sorts; certain others that practically never get away from the commonplace, from the prosaic memories.

Blessed is he whose psychophysical disposition is of the former type. If he happens not to possess this touch of genius, nothing can be done but substitute persistence and methodical trial for the quick advances of the chosen few. No rules can be given for changing the unfertile brain into the fertile one, nor for the better use of the fertile.

In the unusualness of the associations and connections that are made lies the one point of similarity between the abnormal or insane brain and the brain of genius. Both are constantly calling up ideas in connections that would be impossible to the average mind. Tests of the associations of the insane show that their range of associations for a given set of words is very much greater than in the normal group. The results obtained by the man of genius prove the same departures from the commonplace, — in this case called original. The difference between the two sorts of mental fecundity is found in the nature of the originality. In the insane there is little control, the associates are not at all restricted by the nature of the environment, or by any appropriateness to the situation. In the effective man of genius, they are checked and restrained to correspond to the wider demands of the moment. The second still more important difference is to be found in the repression on the part of the normal man of the suggestions that are not suited to the occasion, to the end in view. The speech of an insane man may be merely a ' word salad,' an outpouring of words in any connection ; in the normal these absurdities are inhibited, and if they present themselves at all, only those are uttered that pass the censor. Ability to distinguish

between the appropriate and the inappropriate is the primary mark of the normal as opposed to the abnormal. This serves, too, to emphasize the stages of the inference. One must first have the suggestion that is to constitute the solution, but must also have the capacity of knowing when the right solution has made its appearance. Reasonable freedom in suggestion is desirable, but absolutely essential is the capacity to appreciate the right suggestion when it comes, and to be satisfied with no less than the full solution.

Sometimes the right suggestion comes by chance, sometimes it appears when thinking of something else, sometimes one is merely fumbling with the object that one wants to improve in some way and makes the proper change without any preliminary thought, sometimes it is said inventions have been dreamed. Jastrow quotes an instance of an archæologist who dreamed the reconstruction of the results of certain of his excavations and found that they were satisfactory. It is said that the eccentric on the steam engine was invented by the boy who had been set to open and close the valves when the piston should change its direction. When he saw some boys he wanted to play with, it chanced that he saw a place to put a stick where it would do the work he was doing, so slipped it in and went off to play. Whether the anecdote be true or not, it illustrates how inventions may be made. It makes no difference how the suggestion comes provided it is recognized as appropriate when it comes, for inference is then complete. Obviously it is quite as important to make proper selection from among the suggestions, as it is to have the suggestion. In this respect reasoning

is like memory. The associations that arise in the attempt to recall correspond to the suggestions in reasoning. Passing upon the correctness of the recall found in recognition corresponds to acceptance of the solution. We shall find that many of the action processes have a similar distinction, that many operations involve a process of trial and error in the productive operation, controlled by some means of testing the attainment of the end.

Belief and Proof. — It is particularly essential, then, that we understand this testing or censoring process in connection with reasoning. Two phases may be distinguished. One, belief, is implicit, comes immediately and without any definite consciousness of the conditions that lie behind it; the other, proof, is more explicit, attempts to make clear why the thinker believes, and why others should accept the inference. Belief gives no warrant for itself; one knows only that one does believe, and can tell why only from a study of the conditions under which belief makes its appearance. Neither the feeling of belief nor the conditions that compel belief are fully conscious. In fact, the feeling of belief can be described only in negative terms. We believe all that is not doubted, — the persistent unquestioned presence of any idea constitutes belief. Doubt, on the other hand, comes with alternations in the interpretations, is due to a constant change from one to another of the ways of looking at an object. The cause of the fluctuation is to be found in the changing points of view from which the fact is considered, — in the different complexes of experience that serve to bring up first one interpretation, then another. Thus, if one is considering a general problem,

such as the advantages of controlled monopoly as opposed to unlimited competition, one will think of the advantages of large production, of the encouragement to capital from certain returns, on the one side, and will believe in monopoly; when one thinks of the tendency of human nature to think first of its own advantages and of the growing callousness of the dictator to those dependent upon him, permission to combine seems undesirable, belief in monopoly is refused. The checks that come from state control will remove the doubt for a moment until the difficulties in exercising impartial control present themselves, when the old state of doubt reasserts itself. Doubt is an expression of the conflict in various beliefs, and the beliefs in turn depend upon the presence of various groups of experiences which make for the prominence of one attitude or another toward the assertion that is questioned.

In its less explicit forms belief seems to be an expression of the harmony of a particular statement with the dominant group of experiences. This may be seen to advantage in the changes in belief as different possibilities are considered. When one is caught off one's guard, when a proposition is viewed in the light of a limited group of experiences, one will believe what will not be believed under ordinary circumstances. An exaggeration of the condition is seen in the dream, where we may assume that large areas of the cortex are inactive and only the remaining few control consciousness. Then one will believe many constructions that are rejected as soon as one wakes. In the one case the dream need harmonize only with the partial consciousness,

but as soon as one wakes it is necessary that it harmonize with all portions. This it fails to do and is at once seen to be bizarre. In the play attitude, or in the artistic attitude as in novel reading, one may voluntarily hold part of consciousness out of action and pass upon the game or the work of art in the light of a partial experience. In this mood the result is accepted as true for the moment, although one is aware that it will not seem true as absolute fact. In general, belief is agreement between the construction of the moment and the total experience. The awareness of the agreement no more implies the presence in mind of all of the facts that are involved in passing upon the experience than recognition implies the presence of the associates that give the entering impression a place in the past, or the meaning of an image involves the full presence of all that is meant. Rather the thing believed merely holds the centre of the stage without wavering or opposition, and that, with possibly some slight feeling, constitutes belief.

Proof a Justification of Belief. — While belief is sufficient justification for a conclusion on the part of the person who believes, the conclusion may not appeal so strongly to the listener or to others. This it is that makes proof necessary. Since justifying the conclusion is the one part of the reasoning process that is self-conscious, it is the process that the formal logician has made the most of and which he is inclined to consider the only part of the reasoning process. Two forms of proof are to be distinguished, the deductive and the inductive. The typical deductive proof is through the syllogism, and this consists in essentials of referring the particular con-

clusion to some generally accepted principle, to a general law that is typical of all others. Just as the judgment consists in referring some particular object or difficulty to a typical difficulty or concept, the proof consists of finding a universal statement under which the particular conclusion that has been obtained may be brought and thereby made to seem true. First it should be said that nothing is proved that is not questioned. For one's self belief suffices, and for most of the statements of every-day life as they are made to others no proof is necessary. Proof is given only when one hears or fears objection from one's listeners, or when one desires to test the truth of the conclusion for one's self in an explicit form.

Deductive Proof. — The proof, as given by the formal logician, is in the syllogism, but the syllogism as stated by the formal logician inverts the order in which it is usually applied. One hits upon a conclusion, as was said above, then that conclusion is proved by reference to an accepted general principle. Thus, to use a favorite instance of formal logic, if a member of the Areopagus has thought that all their troubles will be alleviated some day by the death of Socrates, and some one among his hearers questions, he justifies his conclusion by the assertion that Socrates is a man and all men are mortal. There is, of course, no real addition to the knowledge of either in the statement; if there were, it would not be accepted by the hearer, and so would carry no conviction. It takes its value from the fact that it puts in a brief form the common knowledge of the men who listen, and shows that the conclusion reached is but an expression of that common knowledge. The syllogism is usually stated

with the major premise or general statement first, and the minor premise and conclusion following. Thus, our instance would run in its typical form:

All men are mortal.
Socrates is a man;
Therefore Socrates is mortal.

Coupled with this is the belief that the syllogism is itself a form of reasoning, rather than a form of proof. A little observation of the actual thinking indicates that one does not in practice reach the conclusion in this way, but has hit upon it by some less regular process. The syllogism was probably regarded as the form of obtaining conclusions as well as the method of proving them because that is the only part of the operation that is fully conscious; and as reaching the conclusion is most important, it was identified with the conscious operation. The suggestions come by many ways, and are not considered until one begins to question whether they are to be accepted. Then the process of proof becomes fully attended to.

Inductive Proof. — The other form of proof, the inductive, consists in counting instances, in determining how often the conclusion is true. If in the past a solution has worked on every occasion, we are prepared to accept it as true. The proof on this side lies in the actual study of past cases or in experimental repetition and verification of the conclusion. From a study of the vital statistics one knows inductively that all men die. One knows that an aëroplane will fly, because it has flown. The whole proof is one of assuming that what has happened

will happen. In one sense the two proofs tend to come together, since of the empirical proofs only those are accepted that are in every way similar, that can be referred to the same general principle. On the other hand, the general principles that constitute the major premises of syllogisms and the accepted truths are probably in the last analysis derived from experience, but experiences coördinated and tested by particular applications and by their harmony with other general principles. A general principle frequently starts as the result of a few observations, is tested by other observations, then is compared with other general principles that have also been suggested and tested by other single observations, and, if all harmonize, it gradually comes to be generally accepted. In most subjects controversies over general principles are current at all times, because each is in harmony with certain experiences and out of harmony with others. Settlement comes with more accurate analysis of the problem, with more careful study of the facts, and, where experiment is possible, by making crucial tests of each. But in no case is it possible to say that organized previous experience has not played some part in the proof, nor is it possible to assert that observation of particular experiences, induction, shall not have played some part. When reference to generalized old experience is more in evidence, the proof is called deductive; when particular cases, statistics, or experiments play the larger part, the proof is known as inductive, but neither can be completely divorced from the other.

That the stages of reasoning may be as we have stated them: (1) the presentation of the problem that comes by

a thwarting of the progress of action or of thought, (2) the judgment or analysis of the problem into its elements and the reference of each to its appropriate class or concept, (3) the inference or discovery of the solution by much casting about, and finally (4) proof, may be seen by a study of the way in which Darwin and Wallace developed their doctrine of natural selection. It happens that in this case two men, travelling independently practically the same course, arrived at the same conclusion, and we have the process recorded by one of them and confirmed by mutual friends. Dr. Wallace,[1] in modestly disclaiming any priority to Darwin in the discovery, traces in a paper before the Linnæan Society the facts that led both to the discovery of the idea and to its statement. First with reference to the formulation of the problem:

"First (and foremost as I believe) both Darwin and myself became ardent beetle-hunters. Now there is certainly no group of organisms that so impresses the collector by the almost infinite number of its specific forms, the endless modifications of structure, shape, color, and surface-markings that distinguish them from each other, and their innumerable adaptations to diverse environments. . . . Again, both Darwin and myself had, what he terms 'the mere passion of collecting.' . . . I should describe it rather as an intense interest in the mere variety of living things — the variety that catches the eye of the observer even among those which are very much alike but which are soon found to differ in several distinct characters. Now it is this superficial and

[1] The Origin of the Theory of Natural Selection, by A. R. Wallace, Pop. Sci. Monthly, vol. lxxiv, pp. 398 ff.

almost childlike interest in the outward form of living things which, though often despised as unscientific, happened to be *the only one* which would lead us towards a solution of the problem of species. . . . It is the constant search for and detection of these often unexpected differences between very similar creatures, that gives such an intellectual charm and fascination to the mere collection of these insects; and when, as in the case of Darwin and myself, the collectors were of a speculative turn of mind, they were constantly led to think upon the 'why' and the 'how' of all this wonderful variety in nature — this overwhelming, and, at first sight, purposeless wealth of specific forms among the very humblest forms of life. . . . Then, a little later . . . we became travellers, collectors, and observers in some of the richest and most interesting portions of the earth; and we thus had forced upon our attention all the strange phenomena of local and geographical distribution, with the numerous problems to which they give rise. Thenceforward our interest in the great mystery of how species came into existence was intensified, and — again to use Darwin's expression — 'haunted' us.

"Finally, both Darwin and myself, at the critical period when our minds were freshly stored with a considerable body of personal observation and reflection bearing upon the problem to be solved, had our attention directed to the system of *positive checks* as expounded by Malthus in his 'Principles of Population.' The effect of this was analogous to that of friction upon a specially prepared match, producing that flash of insight which led us immediately to the simple but universal law of the

'survival of the fittest,' as the long-sought effective cause of the continuous modification and adaptation of living things."

This shows that the problem had been set for both by almost the same conditions and that the solution had been attained in the same way, but the method of proof devoted to the suggestion was altogether different. Darwin spent thirty years in collecting evidence and in writing out the evidence with only one mention of his theory to Sir Charles Lyell. Wallace, on the contrary, sat down at once, wrote a sketch of his theory, and, curiously enough, sent it to Darwin with the request that it be published. On the advice of friends Darwin presented the paper with a sketch of his own theory to a meeting of the Linnæan Society July 1, 1858. Darwin said that even the words of Wallace's paper were so nearly like his own that one might have supposed that he must have seen it before he wrote. Wallace emphasizes the influence of similar circumstances upon the common result:

"This view of the combination of certain mental faculties and external conditions that led Darwin and myself to an identical conception also serves to explain why none of our precursors or contemporaries hit upon what is really so very simple a solution of the great problem. . . . And now to recur to my own position, I may be allowed to make a final remark. I have long since come to see that no one deserves either praise or blame for the ideas that come to him. . . . Ideas and beliefs are certainly not voluntary acts. They come to us — we scarcely know *how* or *whence*, and once they

have got possession of us we cannot reject or change them at will. It is for the common good that the promulgation of ideas should be free — uninfluenced by either praise or blame, reward or punishment."

In this sketch Wallace marks out explicitly three of our stages, — the arousal of the problem, the hitting upon the solution, and the proof. The second, the analysis of the problem or judgment, can be seen implicitly in the many forms that the problem took as the how and why of the species became prominent at different times. Observation will show that any clearly formulated bit of reasoning takes essentially the same course. Most of the thinking of our daily life, even the important decisions, stop with the implicit belief. The formal justification of the conclusion is not made. But, as was seen, the unformulated but organized earlier experience is at work in accepting or rejecting these conclusions through the immediate belief processes, just as it is in the more formal operations. The warrant is the same although the form in which it is expressed is different.

In reasoning, then, we see an advance made upon the accumulated knowledge, but an advance that is always made possible and controlled by that accumulated knowledge. One understands the new presentation and the new difficulties in terms of the organized old experiences, the types and concepts; one obtains suggestions for new solutions on the basis of analogies with the old; and, when obtained, the suggestions for new solutions are justified and tested in advance of actual use in the light of the organized knowledge. While new experiences and new trials are constantly increasing the sum total of knowl-

edge, it is only by virtue of the previous accumulations and organizations that the new can be understood and that one may venture to test the new suggestions in action with even fair assurance of success.

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CHAPTER XII

INSTINCT

VERY much of the motor and some important parts of the affective and sensory activity of the individual, whether man or animal, are not acquired, but are present at birth or develop at some time during the life of the individual without being learned. We assumed in connection with the discussion of the nervous system that numbers of synapses were open at birth and that these determined the course of many of the early responses. These reflexes are active at all times and play a most important part in keeping the organism alive until learning is possible, and throughout life may be said to care for the essential activities. Respiration, the beat of the heart, and all of the activities of the alimentary canal go on of themselves. They do not require thought to continue them and cannot be stopped voluntarily. The list of reflexes might be continued indefinitely, as they include the regulation of all of the vital processes and the adjustment of the skeletal muscles to the demands of simple stimuli.

Definition of Instinct. — Closely related in many ways to the reflexes and also part of the natural endowment of man are other movements and tendencies to movement, the instincts. Under this head are included a large number of different processes, activities and

tendencies to activities. So general has been the use of the word, in fact, that some writers desire to give it up as too vague. However, so many important facts may be grouped under the term, and the series of activities it describes is so important, that it seems much better to retain the word and to state clearly just what it is and what it is not to mean. Three fairly distinct meanings of the word instinct are current. The first is to designate a more complicated reflex, or one that in its variability in some degree approaches the voluntary act. Thus, the pecking at a grain of corn by a newly hatched chick, and the complicated series of movements by which it breaks its way out of the shell, are instincts of the first type. They are more complicated than the reflex, involve a greater number of muscles, and a larger number of movements in a series. The line between instincts and reflexes, when instinct is used in this sense, is difficult to draw. Just how complicated a reflex must be to be an instinct is not easy to say. It has sometimes been asserted that instincts are more purposive, reflexes more mechanical, but even then the matter is not made much clearer, since most reflexes as well as instincts have a purpose even if reflexes are explained by mechanism. Again, there is always an implication in instinct that we are dealing with something that is or might be conscious, that is like voluntary action. But this is mostly an analogy, and, since instincts are very frequently not conscious, or we can only infer that they are conscious, even this criterion is not susceptible of accurate application. Instinct in this sense is a movement made in response to a stimulus

or a group of stimuli as a result of inherited connections in the nervous system, a movement more complicated than a reflex, either in the number of stimuli that call it out, or in the number of muscles that are coördinated in its execution. In many minds, but subordinate to this distinction, is the further implication that the instinct is purposive, and more like voluntary or conscious movement than the reflex.

A second use of the word *instinct* is much broader and refers, not to some specific response, but to the fact that movements which may vary with surroundings are carried out to the attainment of some general end. This covers a much larger number of instincts in man and the higher animals than does the single simple act or group of acts. Thus, a simple unmodified instinct is that of the solitary wasp noticed by Fabre and quoted by Hobhouse as follows: "A solitary wasp, *Sphex flavipennis*, which provisions its nest with small grasshoppers, when it returns to the cell leaves the victim outside, and goes down for a moment to see that all is right. During her absence M. Fabre moved the grasshopper a little. Out came the Sphex, soon found her victim, dragged it to the mouth of the cell, and left it as before. Again and again M. Fabre moved the grasshopper, but every time the Sphex did the same thing, until M. Fabre was tired out."

Variation in Instinct. — As opposed to this rigidly determined series of movements, most instincts show considerable variation and reach the final end by various ways. The hunting instinct of a cat, as exhibited in catching and killing mice or birds, adapts itself to

the circumstances. Only the crouching as the prey is approached and perhaps the final spring are even approximately uniform. The cat usually plays with the mouse after it is caught, but even this is not a mere mechanical repetition of the same movement or series of movements. The resemblance between acts at different times is at best general, and the reaction is to a number of separate stimuli each of which calls out a separate act, and the whole series is bound together by the general end. Probably, even here, each separate act is the result of a definite stimulus, but the connecting link that makes the whole a single act is found in the preparedness induced in the animal by one act which makes it more readily affected by a stimulus of the same group rather than by any other. The whole may be pictured as held together by an inherited tendency for the acts of the entire series to respond in succession to definite sorts of stimuli. But there is much variety in the way in which the end is reached, due apparently to the fact that instead of preparing the way for one set of responses alone, a number of responses, each of which may lead to the desired end, are rendered more easy. Whenever a stimulus presents itself that excites any of the group of movements, the way is opened for carrying out all of the others.

A third common use of the word *instinct* covers a class of activities which are still less definite in character. In the extreme instances of this class little is determined by inheritance other than that the desired end shall be attained. The attainment may be by any method that previous experience or the acquired habits shall

dictate. Here belong very many if not most of the complicated instincts manifested by the human adult. Acquisitiveness, combativeness, sympathy, and the great mass of instincts that may be regarded as protecting the human individual, the family, and the social group are constituted of movements that have no regularity, but nevertheless drive the individual to a fairly definitely prescribed end. Thus, we speak of mating as an instinct, but the preliminary instinctive responses of coyness, and the whole series of courting activities, whether in the higher animals or in man, are indefinite. At the more reflex end of this class are movements that seem to be directed toward a definite end, but the separate responses are not each dependent upon the preceding act and the stimulus, but are complex mixtures of learned movements with a few reflexes. In simplest form the third class is different from the second only in the fact that movement and the stimulus are not so closely joined. One of several responses may be made to the stimulus. Again, one movement of the series does not follow so mechanically upon the preceding. Finally, the end is more in evidence. This end may be foreseen, although the reason for the dominance of that end or purpose is usually not appreciated. At the other extreme of this third class, what is instinctive is the pleasure that accompanies the attainment of the purpose rather than the concatenation of movements that shall lead to that end. The acts made when one sees a beggar may vary from giving money to turning away as quickly as possible, but the feeling of pain that impels to some action is due to inherited causes. The term *instinct,*

then, is used to indicate all acts whose conditions are inherited. It matters not whether those acts may be referred to specific inherited connections in the nervous system or whether the act is the result of striving for an end which some innate predisposition compels the individual to strive for, and whose attainment gives pleasure. While this definition is broader than that explicitly given by many psychologists, all extend the term in practice to cover acts that belong only to our broadest class. At present most men incline to make instincts primarily reflexes of greater complexity, and to reduce as many as possible to the simpler forms of response. This is the more satisfactory, as it reduces to a minimum the natural tendency to vagueness and the introduction of mystical forces. Even where instincts cannot be explained in this simplest way, there is no need to resort to the mystical, since the dispositions and preparatory irradiations may all be assumed to be due to the inheritance of specific dispositions in the nervous system, even if we cannot at present say exactly in what they consist.

Classifications of Instinct. — The specific instincts are differently classified, and no complete agreement exists as to what shall be regarded as instinctive, even when the definitions have been settled. MacDougall limits instincts to flight, repulsion, curiosity, pugnacity, self-abasement, self-assertion, and the parental instinct (under which are placed care of the child, sympathy as an outgrowth of care for the offspring, and, by development, moral indignation). Minor instincts are reproduction, gregarious instincts, construction. Watson

in his study of animals has eleven classes, — locomotion, obtaining food, shelter, rest, play, sleep, taken together as the basis for the daily and seasonal routine; sex, defense and attack, migration, mimicry, vocalization; and two less definite groups. Some add more, others question some of these, but there is probably no chance of close agreement among all as to just how many groups there are, or even what specific acts shall be included in any group.

We may do best to make a general classification with reference to the end that the act subserves, rather than to the specific character of the particular instinct. One of the most convenient divides instincts into three classes: 1. those which preserve the life and provide for the welfare of the individual; 2. those which provide for the continuance of the race and for the family; and 3. those which make for the welfare of the tribe or of the social unit. Some of the acts belong to more than one class, — in fact, no one of the second or third would be possible without the first, — but the division is convenient in general and may serve as a guide through the maze.

Individual Instincts. — Among the individual instincts we have those necessary to care for the individual in the early stages of life. One of the best instances is found in the pecking its way out of its shell by the young bird. This instinct, according to Craig, is always carried out in very much the same way although involving a number of separate movements, pecking itself, and so turning in the shell that the shell may be broken in a continuous ring. Here, too, belong the first movements

of taking food, which make their appearance almost at once, and change their character as the needs of the organism develop. Other individual instincts are involved in locomotion, walking, flying, or swimming, the care of the body in matters of cleanliness, the preening of the feathers by the bird, licking the body by cats, dogs, etc., the persistent hunt for parasites that seems to occupy a large part of the spare time of all monkeys and apes, stalking game, fighting, flight from larger animals, in sum an imposing list. In man the number is no less great, and each of the simpler names includes in most cases a larger number of different acts. Some of the more complicated acts that play a large part in determining the character of the man and many of his most important qualities are flight or fear, pugnacity, collecting materials of all kinds from money to postage stamps, rivalry with its accompaniment of envy, curiosity, and, possibly, constructiveness, although the latter may be a compound of other instincts. Similarly, laughing and weeping with simple forms of vocalization probably belong among the instincts.

These instincts seem to be present in some degree in all men. Some, however, are more striking for their universality, others because they are present in such different degrees in different individuals. Thus, fears show themselves in practically all, although to be sure in different forms and in different degrees. In most cases these are not to be explained from experience and many are absurd in the light of experience. Why a grown woman should be so startled by a mouse, why a man should make such exaggerated responses

when a harmless snake wraps itself around his ankle, are hard to understand in the light of experience alone. Similar are the trembling at looking over the edge of a precipice from behind a perfectly secure railing, the fear of the dark, of caves and strange places, of the dead, and hosts of others that the reader may supply from his own experience. In the development of a child, these fears come one after another and frequently disappear almost as suddenly as they appear. For a few weeks or months a child will be afraid of furs, then the fear disappears and fondness for it replaces the fear. A cat may suddenly become an object of terror and later, without other experience of cats, may arouse all signs of pleasure. Thus, the early life may be a constant succession of fears that come apparently with the stages of development of the nervous system. Interesting, too, it is to note the tendency of those fears to become exaggerated in diseased conditions of the central nervous system. Here we find fear of open places that leads the victim to slink around the sides of parks rather than walk across them (agoraphobia), and also, the opposite tendency, to fear all closed places, to avoid rooms and narrow streets, and to feel at home only in the open (claustrophobia). These are but two of many morbid fears.

Among the instincts that aid to make up the individual character by the amount they contribute to the sum total of his instincts are pugnacity, the tendency to accumulate, and curiosity. The degree of pugnacity is one of the most important individual characteristics. It varies from the extreme in a tendency to domineer

over every one, through a moderate degree of self-assertion, to an extreme in the weakling who never asserts himself. The one man never admits that he is wrong, will never see that he is beaten, but fights on to the end. Tempered with proper discrimination of what is worth fighting for, this constitutes one of the elements in all strong characters; untempered, it makes the quarrelsome bully. The man in whom it is badly developed is ready to give up with the first disappointment, if he permits himself to get involved at all. Closely related, if not identical, are the qualities of courage and cowardice. The collecting instinct is not quite so clearly demonstrable as an instinct, but the piling up of hoards of all kinds beyond the probable or even the possible needs of an individual seems to demand an explanation other than habit. The intense pleasure which comes with the large accumulation is indicative of other than acquired characteristics.

Curiosity is a striking character in the attitude of the higher animals as well as of men. The dog, the cat in less degree, monkeys in the extreme, show a tendency to examine all strange objects. From their acts one might argue that they were intent on understanding them. Certainly in man there is a pervading restlessness until all unfamiliar objects and movements have been examined and explained, — an instinct that shows itself early and persists with increasing intensity until well into old age. In its simple forms in the child or in the uncultivated it impels an investigation of all possible sources of danger and provides for the security of the individual. In its higher forms it may well be regarded

as the source of very much of man's desire for knowledge and of the growth of science developed from it. Much of this knowledge is probably useless from the practical man's standpoint, and in any case the investigations that lead to the discoveries are most frequently carried out for the sake of the knowledge itself, rather than from any intention of obtaining practical benefit. The background and foundation of the individual's character are to be explained in large measure from the degree in which he has instincts. They determine in some measure what shall appeal to him and, in still larger measure, the amount of effort that he devotes to attaining the end that appeals.

Race Instincts. — No less important in the adult life are the race instincts. The mating instincts give illustration both of the definite but complicated response, and of the vaguer movements determined only as to their end, or even by the pleasure that comes from the attainment of a given purpose, with little control of the method of attainment. The manner of the manifestations of the courting impulses is, in man, not at all a matter of conscious purpose. The display and boastfulness of the male on the one hand, or his bashfulness in the presence of a chosen member of the opposite sex, on the other, is in most cases not intentional, and cannot be prevented at will. The coyness of the maiden is equally removed from voluntary control. Even more widespread in their effect upon society are the activities and feelings involved in the care of the young and in keeping together the family. In man these processes are largely indefinite. They are guided by the

pleasure of the parent in the welfare of the child. Most of the actual movements are learned through education and developed by habit. Only the pleasure produced by the achievement of the end and by the presence of the child is really instinctive; the rest is habit. In the lower animals of course the instincts are much more definite, as in the building of the nest, in determining the kind of food that is given, and the way it shall be given. Even here, however, much is left to the control of circumstances, for the processes cannot be reduced to a mere chain of reflexes. In man the continuous association and the care for the welfare of the members of the family constitute an important element in the development of unselfishness in general and of all the ideal elements in character.

Social Instincts. — The widest group of instincts, the social, are least often expressed as definite responses on the level of reflexes, and most frequently are merely goals imposed by feelings of pleasure or the reverse. Simple gregariousness is most frequently shown in the lower animals and is not without its analogues in man. The bison or reindeer or the wolf, under certain circumstances, seems to feel pleasure in merely being with others of his species. The same instinct may be seen in men who feel pleasure in being in the crowd on a city street, even if there be no words spoken and no intercourse of any kind with the members of the crowd. One may be absolutely alone, even avoid conversation with his fellows, and at the same time feel pleasure at their presence, or at least feel a haunting and unconquerable loneliness when away in the wilderness or where

his fellows are not to be found. Obviously this instinct finds no simple expression in action, but is due merely to the pleasant feeling of being with others or to the displeasure of being alone. The individual may and usually does definitely plan the movements that will take him to a place where people are likely to be found, but the tendency to dwell fondly upon the idea is instinctive, as is also the restlessness that may persist without awareness of its cause until other human beings chance to come.

Still more important is the sympathy that compels us to suffer with those who suffer even if we are jealous of those who rejoice. It is this that makes for self-sacrifice in all of its forms in behalf of those beyond the immediate family; it prevents cruelty on our own part and enforces giving aid to those who suffer at the hands of others or as the result of natural forces. It can be seen in the gregarious animals who exert themselves and even suffer in behalf of the herd, as the male deer are said to form a circle about the females and the young and to risk their own lives in defence of the unit. This instinct may be justified teleologically, since the survival of the individual and especially of the race depends upon the survival of the larger group. In man the most striking feature of the instinct is the limitation put upon the group included in its manifestations. It may and has been regarded as an extension of the racial instinct, the instinct to protect the young, but it includes, with a force that diminishes with its extension, an ever-widening group of individuals. The members of the particular social set stand next to the family, then the individuals of the same class. The further extensions

may include the ever-widening circle of political divisions, it may be drawn in some degree in terms of religious or party affiliations, — in fact, any common belief or common purpose may serve as the bond of union within which the instinct of sympathy may act. In these divisions any common ideal, particularly any common ideal that has opponents, may serve as the basis for the organization of a group within which the bonds of sympathy are effective against all outside it. These different lines of organization may cross in many ways. One's fellows in social position may be opponents in politics or religion, but the bonds of sympathy hold in one respect or within one group when the same individuals are separated in other respects. These groupings, with the consequent feelings, constitute the essential facts in any understanding of social organization. In the widest form, the instinct includes all individuals, and thus makes possible the highest development of civilization. Only in the actions called out toward members of the accepted social group is it possible to assert that we are dealing here with an instinct. What shall constitute the group within which the instinct works is determined almost altogether by education and tradition. With mutual knowledge and increasing numbers of common interests the number of individuals that may be included in a social unity has grown beyond the bounds of any one country. But on the other hand, a widespread war will suddenly make rearrangements of this grouping, will put beyond the pale many individuals who have up to that moment been most intimate members of some common group. The strong

bonds between the socialists of all nations that existed before the great war were suddenly broken by it. Thus, while instinct determines the treatment of the members of the common unit, education and experience determine who shall constitute the members.

The interest of man in his fellows in general, and his desire for their approval, are also instinctive. This is in the last analysis the basis of social pressure of which we have made so much in connection with selection in all of its phases. The force exerted is not in any sense physical. The man may be neither better nor worse off on account of the opinion held of him by society, but innate tendencies give the opinion of society a force that he cannot overcome. These influences hold the man in his accepted place, keep him to his allotted task in moments of weariness, prevent eccentric acts and remarks, are the forces that make society possible, even if in very many cases they make convention dominate originality. In the individual they serve as spurs to many of the activities with a more remote purpose, they give the ideal and unselfish aim an approximation to equal standing with the material and the selfish.

We may look to instinct for many of the springs of the phases of conduct which we cannot understand from the immediate circumstances or the earlier education of the individual. Through them he is spurred to the avoidance of dangers that he does not know, is impelled toward the attainment of rewards that he cannot foresee. Where he recognizes the goal and the purpose of the act, he, through instinct, is impelled to bodily reactions that he does not understand and which appar-

ently have no meaning for the act itself. He trembles, he weeps, he smiles and glows with warmth, adjusts his tones to the mournful or the exultant key, all, so far as he can see, without reason. The insect lays its eggs and provides for the nourishment and protection of its young which in many cases it is never to see. In man the acts necessary for the propagation of the species are with more knowledge of the purpose, but nevertheless many of the details of conduct in that connection can be given no explanation from experience alone, and the strength of the impulses can be understood only from forces beyond experience, and often opposed to reason. Balancing these in many respects are the social instincts which enlarge the circle of objects of instinctive acts and make the individual sensitive to the demands of the community with its laws and traditions.

Instinct and Learning. — It must be remembered throughout that instincts never show themselves in isolation or in pure form. They are always mixed with the reflexes on the one side, and with habit and even with reason on the other. The distinction between reflex and instinct is hard to draw. Even when it has been decided that an activity belongs to the class of instincts, reflexes are always present to determine the execution of the individual acts. Almost if not quite all instinctive acts are also influenced by learning. Even so simple an act as the chick's pecking at a grain of corn is not performed the first time in full perfection and, in the more complicated processes, the instinctive and experiential factors can with difficulty be isolated. In one set of experiments the first attempts at pecking

on the second day of the chick's life gave ten correct responses out of fifty. This increased to an average of a little less than forty by the seventh day, from which stage the progress was comparatively slow. While mere growth with age is important, still practice is necessary in all cases, as is shown in experiments by Breed and Shepard. They kept chicks blindfolded for periods varying from birth up to five days and found that the number of correct reactions the first day of practice was no greater for the older than for the younger, but the older made more rapid progress. By the eighth day all were on approximately the same level, irrespective of the number of days of practice. In the more complicated acts of the higher animals, instincts are still more dependent upon training and habit formation. Birds kept in isolation do not ordinarily develop the peculiar song of their species, but a new one. On the other hand, where young birds are kept exclusively with older birds of another species, they learn the song of that species within the limits of their own vocal capacity. Even the English sparrow will approximate the song of canaries if kept near them from birth. Heredity, it seems, provides nothing but the organs and the possibility of forming suitable connections, together with the tendency to use the vocal apparatus in any necessary way. All else is determined by the practice of the individual, guided by the sounds that are heard.

In man, instinct is still more mixed with habit and all the more rational and voluntary processes. Language is not instinctive as a specific process. As in the bird, what is instinctive is the organization that makes sounds

possible, the instinct of making sounds, with no reference to the kind, and the desire for the approval of his fellows which makes it desire to repeat the sounds. These together suffice to develop in the child the language of the people with whom it is thrown, by whom it is reared. Even the simplest instinctive acts are not performed at the first trial in their full perfection. Both practice and intelligent guidance are needed before great accuracy is attained. Here learning is hard to separate from the natural growth of the individual. The sex instincts appear in full vigor only as the individual approaches maturity. Other instincts come in part at least through the growth of the nervous system; they unfold one by one as the corresponding growth takes place. Still, it must be insisted that practice plays a part in the development of many instincts in man as it does in the pecking of the chick mentioned above. Furthermore, if the instinct is not used when it makes its appearance, there is some evidence that it may fall into disuse and fail to exhibit itself later when occasion arises. Instinctive movements depend upon learning for their development, take on much of their specific form through practice, and, in some cases at least, disappear unless used.

Imitation and Play. — Specific instances of the way in which instinct and learning coöperate can be well illustrated by imitation and play, often spoken of as instincts. As a matter of actual observation we find imitation playing a large part in the life of man and the higher animals. On analysis, however, it is not possible to say that imitation is itself an instinct. The variety of movements involved is too great to bring it under the head of a

complicated reflex, and, so far as one may regard it as a search for a goal determined by the pleasure of the attainment of the goal, nothing more is needed to account for it than the general instinctive pleasure of social approval to supply the end and interest in the other individuals of the species and in their acts to induce attempts to perform the specific act. Thus, when the child learns to speak, it may be said roughly to be through imitation, but analysis proves that the child has an instinct to make sounds of no particular character. When by chance these result in words, the parents recognize and repeat, and give evidences of pleasure that lead the child to attempt to say them again; or the child may himself be vaguely conscious of the similarity of the sounds he makes to words that he has heard and so be more interested in them than in the other sounds. In any case it is the instinctive pleasure in sounds from others of his kind, and the approval they give to his own efforts, that lead to the repetition of the sound once made. Imitation in older individuals and of movements that are already known in their elements can also be traced to similar general instincts.

Play also is an expression of many instincts rather than of a single one. The tendency to play can be looked upon as a result of the general tendency to action, to motor discharge. The character of the discharge, the particular play indulged in, is determined, in part by the environment and by the general social instincts, and in part by a host of particular instincts. Thus, playing with a doll is partly imitation of the mother, partly an early budding of the maternal instinct; the

hunting and fighting plays, the constructive plays, all forms of rivalry and competition are but the exhibition of different instincts under make-believe conditions, under circumstances assumed to exist for the sake of the play. At most, play is no single instinct but the expression of a host of instincts under the pressure of a general tendency to act, to find an outlet for a reserve of energy under the effects of stimulation. The value of play in developing capacities through practice in advance of the actual necessity is obvious.

The Origin of Instinct. — The origin of instinct is primarily a problem for the biologist. Instincts are nervous dispositions that have been developed in the different species and are then inherited. The way in which instincts might arise has attracted most attention, as the inheritance is largely taken for granted. The opposing general theories of evolution, the theory of acquired characters and of natural selection, have been applied to its explanation. For psychology either theory suffices. It would be easier to explain instinct as the inheritance of the tendency to make movements that have been repeatedly made by the ancestors, but a majority of the biologists are at present sceptical of the possibility of such an inheritance (the inheritance of acquired characters), and psychology has no evidence of its own to offer in its favor. Certainly no specific acts that have been developed in a high degree by the father exhibit themselves in the child, and when any particular capacity of the father can be detected in the child it is doubtful whether it is not due to an inheritance by the father rather than to his particular training.

Barring inheritance of acquired characters, instincts must be due to the selection of the individuals who chance to develop those favorable to survival. The cause of the change in the germ plasm that produces the favorable instinct is not at all determined. It may be due to some chemical action, as in some cases it has been shown to be induced by physical stimuli; but given the change, however it arises, it tends to persist in the later generations. All that the doctrine of natural selection asserts in addition is that those organisms which chance to develop tendencies to action favorable to their survival and to the continuance of the species will increase in numbers, and those which fail to develop this tendency will die out and their instincts will die with them. As a result of this selection in the course of the ages and innumerable generations of individuals, we find man a being provided with many of the structures essential to his present method of living, as well as many that are left over from stages in which they may have been useful, but are now at best not harmful. Similarly, selection has given a nervous system with connections and predispositions that are on the whole adequate to the direction of the bodily structures, although there are some, those at the basis of many of the fears, *e.g.*, that might easily be dispensed with.

In conclusion, we must assume that there are a number of the most fundamental reactions and demands of the organism which are present in it from birth and serve as a foundation for the superstructure of learning. In part these are specific acts or groups of acts, in part they make their effect felt as ends towards which the

organism must struggle by whatever movements it may have at its disposal. There seems to be a possibility of making either the movements that are aroused through instinct, or the feeling that accompanies the movement, fundamental in the explanation of all instincts. In the one case, each situation would call out a definite response, and, where the obvious response was lacking, it could be assumed that it was still present in some obscured or unnoticed form. On the other hand, it might be assumed that what is instinctive is the feeling, — the pleasure that accompanies the instinctively determined proper end, and the unpleasantness or restlessness that persists until that end is attained. As has been seen, one theory would hold very satisfactorily for one type of instinct, the other just as satisfactorily for another. It seems more in harmony with the facts and, on the whole, to offer less difficulty for the theory to assume that both the movement and the feeling are accompaniments or results of the single biological predisposition. At the lower level the movement, at the upper levels the end which asserts itself only because it is pleasant when attained are the more frequent characteristics of the instinct. This leaves much to be explained, but it does permit the use of the word in the broad sense, implied if not explicitly adopted, by modern psychologists.

In instinct we find the source of most of the movements and many of the feelings that we cannot explain by immediate stimuli or from the earlier experience of the individual. It not merely provides the germ which is later developed into the complicated movements, but

also many of the strongest incentives that we have in connection with our most complex voluntary and rational life. If one ask why one is afraid of the dark, why the mysterious thrills, the answer can be given only in terms of instinct. Similarly, if one ask why to acquire wealth, or to invent a new machine, or discover some new truth should be of almost universal appeal, we can again reply only in terms of instinct. If one seek an explanation of why one falls in love and of many of the actions, particularly of the thrills and blushings and tones peculiar to that state, one must look to instinct. Finally, and most important of all, the social instinct supplies the desire to be popular, to seek the approval of the fellows upon which depends the force of social convention, and which drives to work when individual need and individual instinct exhaust their impelling power. If this extreme statement would seem to make everything worth while only because of its instinctive appeal, it must be remembered that instinct is developed, modified, and even restrained through experience and reduced to conventional type by social pressure, itself an expression of the social instinct. Certain it is that very many of the phenomena in connection with feeling and action and particularly in emotion can be understood, if they are to be understood at all, only in terms of instinct.

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CHAPTER XIII

FEELING AND AFFECTION

The first of the processes that are in part explained and in part presupposed in instinct, is feeling, the tone that colors very many of our mental states. The principal difficulty in the discussion of feeling lies in the fact that the term has no exact and definite meaning, or perhaps more truly has a number of meanings, no two of which are altogether reconcilable and which are held by different men of nearly equal authority. Feeling was originally used to indicate approximately the same mental states as sensation. We still use the term popularly as synonymous with the sensations of touch and of organic sensations. It is also used to indicate any conscious state which is relatively vague, *e.g.*, to designate intuition as opposed to the more explicit ways of reaching conclusions by reasoning. We also use the term technically for any less definite conscious state. Thus, we talk of a feeling of interest, a feeling of recognition, a feeling of belief, and many similar states. These states are definite enough as ways of being conscious, but their conditions are less in evidence than those of sensation. The term *feeling* is used popularly and has been used at different times for a number of different processes which have nothing in common except their vagueness, either in the state itself, in its reference, or in its conditions.

Definitions of Feeling and Affection. — Evidently we cannot use the term in all of the ways enumerated, and we are the more justified in restricting it by the fact that there is a fair consensus of opinion among psychologists who have written recently that we shall use it to designate a single process or pair of processes commonly known as pleasure and pain, or more accurately pleasantness and unpleasantness. Since the bare feeling is never found alone but is always accompanied by sensation, it is necessary to distinguish the simple element from the complex of sensation and feeling. Thus, in a headache there is a definitely localized sensation or mass of sensations, and in addition we dislike the ache. The dislike itself, or the form that it takes as a mental process, is the affection, the unpleasantness. No one would deny that this is quite different as a conscious quality from the sensation itself. This quality with its opposite is what is defined as affection. The complex of affection with sensation is known as a feeling. Psychologists thus distinguish affection from feeling for their technical usage. Affection is the bare fact that we find an event pleasant or unpleasant, while feeling is used to indicate the complex of sensation and affection. Thus, in the instance above, the mere unpleasantness of the experience connected with the headache is the affection, while feeling is the term applied to the total experience. What is meant by this state can be understood by all, but can be accurately defined or described by no one. In the attempt to make clear what is meant, we must recall what was said concerning concepts. What we desire to do is to indicate a concept, which, together with the concept of sensation,

shall serve to make possible a description of the most general phases of our conscious life, and to which we may refer concrete states as they present themselves to indicate certain aspects of many of our mental processes. To make this reference is all that can be done in the way of analysis, and is helpful in all descriptions and discussions. Sensations or affections are said to be the elements of consciousness, but that does not mean that they are ever found separately. All that is meant is that it is possible to discover in mental states a sensational phase and an affective phase, — that certain states are similar by virtue of the fact that they are pleasant, just as certain others are similar by virtue of the fact that they are green, and still others in that they are square. For convenience, then, we have spoken of sensations as independent existences and will speak of affections in somewhat the same way, as if affections were elementary conscious states and that mental states might be compounded out of them, as substances are compounded out of chemical elements.

Affection and Sensation. — In justifying a separate discussion of the affective phase of consciousness, we must meet two objections. First, it has been held that feeling is only a special kind of sensation; second, that affection is not a distinct element at all but merely an attribute or accompaniment of sensation. To the first suggestion it may be objected that affections are unlike sensations in that they have no special sense organs. Pleasure may come as the result of the stimulation of any sense organ, and displeasure similarly may be the accompaniment of many different kinds of stimulations and be excited

through many different sense organs. The argument for the specific sensations of pleasantness and unpleasantness seems to have been developed on the assumption that pain and unpleasantness are identical. As we have seen, there is a special sense organ for pain in the skin and other tissues, and if pain and unpleasantness are to be considered identical, the sense organ for both is readily supplied. As a matter of fact pain and unpleasantness do not mean the same thing. Pain is the specific sensation, and unpleasantness the accompanying reaction. One may see this most clearly, perhaps, from the fact that pain is not necessarily unpleasant. Without speculating as to the pleasure of martyrs, we find numerous cases in which slight stimulation of pain spots is pleasant, as in the cold of a bath, or the fascination of pressing gently upon an inflamed spot. While pain in slight intensity may on occasion be pleasant, it is not at all infrequent for unpleasantness to accompany other mental processes in which there is no excitation of a pain nerve. Smells are unpleasant when there is often none of the sharpness that represents the excitation of cutaneous sense ends. The odor of decaying flesh is unpleasant in itself as opposed to the unpleasantness of ammonia or chlorine which is in part due to the excitation of pain nerves in the mucous membranes of the nasal passages. Unpleasant combinations of colors or of tones belong in the same class as do the unpleasant effects derived from unpleasant spatial and temporal relations, the unpleasant ideas from social wrongs, etc. One finds a long list of unpleasantnesses that cannot be referred to sense pains.

If pain be not identical with unpleasantness and the

pain nerve be not the organ of the unpleasant affection, still less is it possible to find a specific sense organ for pleasantness. It has been suggested that tickle may be the pleasant quality and that there is a specific sense organ of tickle. This latter statement, however, is very questionable. Tickle spots have now and again been reported, but the report has seldom been confirmed, and has never been generally accepted. Granted the existence of the tickle spots, the same objections hold to identifying tickle with pleasure as against identifying pain with unpleasantness. Tickling may be unpleasant and many different kinds of pleasure have no resemblance to tickling. Evidently even if we grant the existence of the tickle spots, pleasure must be something more than a peculiar cutaneous sensation, just as unpleasantness is distinct from and in addition to pain.

Other objections to identifying affection with sensation may be made on the basis of the accuracy of localization of the affections. Sensations always have a definite place, while affection is not definitely localized. One is displeased or pleased in no particular part. Exceptions have been taken on the basis of organic sensations, but organic sensations are rather incorrectly localized than unlocalized. Another distinction that rests on a slightly less certain basis but is probably generally valid is that sensory processes are more objective, while the affective processes are more subjective. Sensations usually are referred to the outside world, while feelings are peculiarly personal, peculiarly one's own.

Closely related to this are differences with reference to the effects of attention and the influence of recall. It

seems fairly well assured that attending to a feeling tends to diminish rather than to increase it, while, as was seen, attention increases the effectiveness of sensations. In passing upon this statement, one should be careful to distinguish between attending to the stimulus or to the sensation, and to the mere accompanying pleasantness or unpleasantness. If one think of an aching tooth, the pain is increased and the accompanying unpleasantness with it. If, however, one attempts to introspect, to ask how and why this sensation is unpleasant, one will be likely to find that the unpleasantness diminishes as one becomes interested in watching the feeling, and it may disappear altogether. An unpleasant situation bravely faced tends to lose much of its unpleasantness. The same may be said of pleasantness. In practice a constant search for pleasure defeats its end. As one attends to a pleasure it tends to diminish. Lives spent in pleasure-seeking seem never to attain their goal. The only way to make sure of pleasure is to keep in mind some end to be accomplished and let the pleasure come as an incident to its attainment. Keeping pleasure itself in mind destroys it, while attending to the stimulus increases pleasure as well. The objective and subjective difference may be said to be one phase of this influence of attention. Objective processes, when attended to, increase, while a purely subjective process, particularly if that be related in some way to attention itself, would not be increased. If one think of feeling as an effect of attending to a stimulus, it would follow that when attention was not fixed upon a stimulus, at least one condition of feeling would disappear and the feeling with it.

This subjective character of feeling has also been connected with another character or alleged character of feeling, viz. that it cannot be remembered. It is asserted with some warrant from observation that feelings are not recalled. This statement must be carefully guarded and restricted if it is to be accepted. The warrant for it is to be found in the fact that feelings toward an event are likely to change between the time the event is experienced and the time it is recalled. Thus a social *faux pas* that caused extreme embarrassment may later arouse only amusement, and a practical joke that was much enjoyed at the time may be recalled with chagrin. The affection alone is not recalled in these cases, but the event is recalled, and the feeling aroused depends upon the circumstances at the moment of recall. This does not mean that one cannot remember that one was pleased or displeased on the first occasion; on the contrary, but the affection is not reinstated. The memory of how one felt is indirect, is in terms of words or the memory of the expression. The feelings are not reinstated as the sensory elements may be, but are merely represented or meant. The feeling at the time of recall is the expression of the present attitude toward the event rather than of the earlier attitude, the attitude when the event was really experienced. All together there seems little probability that affections are merely separate sensations. Pain and unpleasantness are distinct, and pain seems the only sensation that could in any degree be confused with either pleasantness or unpleasantness. Pleasant sensations have no existence; *i.e.*, there are no sensations to which the term pleasantness could always and regularly be applied that do not

have a distinct sensation quality in addition. To assume that any of these sensations could be regarded as identical with the feeling qualities is out of harmony with the facts of distribution, as well as with the qualities of both sensation and feeling. The more definitely qualitative differences, the different influence of attention, and the difference in the way they are affected in recall, all reënforce this conclusion.

The suggestion that affection might be an attribute of sensation meets with just as grave difficulties. As Külpe has suggested, it is always true of attributes that when one vanishes or is reduced to zero, the sensation also disappears. Sensations with no affective tone are, on the contrary, relatively common. A sensation may be indifferent and still be a sensation, while a sensation that has no quality and no intensity ceases to exist. Also, affections have attributes of their own that vary independently of the attributes of sensation, which again is inconsistent with the assumption that affection is merely an attribute of sensations. Affection has duration, intensity, and quality, is unpleasant or pleasant, although it has no extent or position. On the affirmative side of the question, it must be granted that we apparently never have affection without some sensation, and so it is not an entirely independent entity. One never feels vaguely pleased or displeased: there is always some sensation as the occasion for the affection. In certain instances the affection seems the dominant element in consciousness, but slight observation indicates that there are also sensations, usually of a vague organic character, that serve as the excitant of the feeling. But, as has just been said,

this same sensation may at times be present in some degree without any accompanying feeling or, on occasion, with a feeling of the opposite character. On the whole, it seems fairly safe to conclude that the qualities of pleasantness and unpleasantness are found in close dependence upon stimulus and sensation, but nevertheless constitute what may be regarded as an independent mental state, or, to speak more conservatively, as a phase of consciousness which cannot be understood if we regard it as merely sensation alone, or as an attribute of sensation.

Treating our topic from the structural point of view, affection constitutes a type of mental process that is distinct from sensation but is nevertheless dependent for its existence upon sensation, certainly upon the excitations that cause sensations. Pleasantness and unpleasantness come as a result of sensory excitation immediate or recalled, and these excitations produce sensations at the same time or a little before they give rise to the affections. It is probably true that no excitation gives rise to an affection without also arousing a sensation. The occasional periods of vague well-being or vague ill-being without apparent sensational basis are rare, and in all probability merely cases in which the affective aspect of consciousness has for the moment overshadowed the sensory. While affection is thus dependent upon the same excitations as sensations and even probably dependent upon the sensations themselves for its existence, it is not a mere attribute or phase of the sensation as are quality and intensity; rather we must regard it as a separate mental state or process with attributes of its own.

Qualities of Affection. — Starting from this assumption, we may consider affection in its relation to the various stimuli, enumerate its qualities and its physiological accompaniments, in much the same way as we have treated the cognitive processes. First, with reference to the qualities of feeling, it may be asserted that there are but two, pleasantness and unpleasantness. Many objections have been raised to this statement. In the first place, as has been seen, many people mean altogether different kinds of mental processes, intuitions and what not, from those that we have admitted into the class. These we may exclude by mere arbitrary definition. They certainly have an existence and a place in psychology, but fall rather under reasoning and other heads than under feeling. They simply are not sufficiently like the processes we are discussing to make it possible to extend the term to include them. Wundt, using the term in somewhat our way, makes the suggestion that there are many different qualities of feeling, one for each sensation and intellectual process. To this the majority of psychologists stand in direct opposition. It is frequently asserted that purely sensuous pleasures, such as the pleasures of the table, are of the same quality as those from a beautiful picture or from intellectual or moral satisfaction. The differences that strike one are due rather to the qualities of the accompanying sensations than to the feeling qualities themselves. If one can abstract from the sensational elements, the remnant of pure feeling is always the same.

Pleasantness and Unpleasantness the Only Qualities of Affection. — This is opposed to many authorities, an-

cient and modern, but the distinctions they draw seem to be based on other than psychological grounds. Thus, the moralist of everyday life draws a distinction between higher pleasures and lower pleasures. One is the pleasure from the simple senses, the pleasures of eating, *e.g.*, particularly the pleasures from the satisfaction of the simpler instincts, while the higher pleasures are the pleasures of the imagination, æsthetic pleasures, the pleasures from moral acts. In general, they are the pleasures which society approves, while the lower pleasures are those which are either disapproved or regarded as morally indifferent. This distinction is recognized by every one. It is at the basis of one of Dr. Johnson's favorite distinctions between pleasure and satisfaction. Still it is generally believed not to correspond to any real difference in psychological quality, but rather to a distinction based upon ethical considerations. Sensuous pleasure is believed to be of the same quality as moral pleasure, the pleasure from a pleasant odor of the same quality as that from a painting by an old master. The difference is to be found in the fact that one is approved by the connoisseur, carries with it a certificate of being beyond the ken of the multitude, and takes an added flavor from that fact, a flavor which may intensify the other quality but is of the same general class or type. Other suggested qualities of pleasant and unpleasant seem on analysis to reduce to similar extraneous considerations and to leave but two qualities, pleasantness and unpleasantness. In general, one must admit with Wundt that the total feeling varies with each stimulation and with each sensation or

memory or other sort of mental state, but the variation is not in the affection but in the sensational accompaniments. The pleasantness or unpleasantness is, if we are to believe the introspections of the large mass of psychologists, always identical, and the differences that Wundt insists upon are to be found in the cognitive accompaniments. The differences between sensuous, æsthetic, and

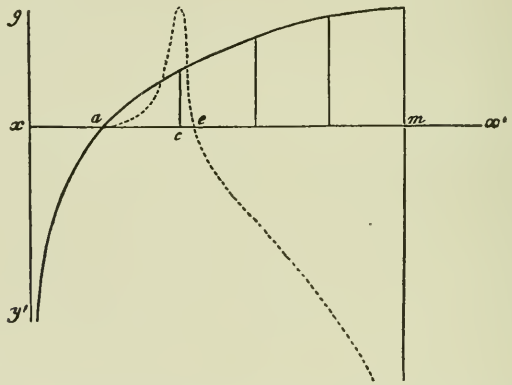

Fig. 89. — Schematic diagram of the relation of affection to sensation. The smooth curve shows the rise of sensation with intensity of stimulus, the dotted line the accompanying rise and fall of pleasantness and the increase of unpleasantness. (From Wundt.)

moral pleasures or displeasures are in the occasions of the affections, in the cognitive component of the feelings rather than in the affective elements themselves.

The other attributes of affection deserve but a sentence. The intensity of each quality of affection varies from zero to a maximum that may end in the loss of consciousness. The relation to the intensity of stimulus has been expressed by Wundt in a curve that holds for stimuli of certain kinds, although there may be exceptions. A faint

stimulus is usually indifferent. As the intensity increases, a pleasant affection begins and increases to a maximum with moderate excitations, and then drops to indifference, and finally becomes unpleasant as the excitation is increased still more. Where pleasantness disappears varies with the nature of the stimulus. In many cases it is at a very low point in the scale of intensities; for other qualities all but the highest intensities are pleasant. With suitable allowances, practically all sense qualities will be found to correspond with the rule in some degree. It at least approximates a law. In the diagram the line *a* indicates the increase in sensation by the logarithmic curve in accordance with Weber's law; *e*, the curve of increase in intensity of affection, above the line indicating pleasant, below the line unpleasant affection. The duration of affection varies from the duration of the stimulus both at the beginning and the end. Affection, as was said above, lags behind the stimulus, appears later, a little after the sensation even, in most cases, and may either disappear before the stimulus or change its tone as the stimulus persists. Thus, stimuli which at first are pleasant may become indifferent or become unpleasant if they last too long. Duration has much the same tendency as intensity in this respect, and one might draw a similar curve. The tendency is always for the feeling to become unpleasant rather than pleasant as its duration increases. No general rule can be given even for the same stimulus as to how great the duration must be before the quality will change.

Other Suggested Pairs of Feelings. — Wundt and Royce assert that there are other definite opposites of

consciousness that must also be classed as feelings. Royce adds two, restlessness and quiescence. The one is said to be characterized by a constantly changing impulse to movement, particularly by a feeling that one must get on to do something else; while quiescence implies an assent to the present condition, a readiness to remain in the condition in which one is. Wundt affirms that there are three pairs of affection which may be regarded as constituting a three-dimensional series. To pleasantness-unpleasantness he adds strain and relaxation, excitation and quiescence. Strain and relaxation are related to the feeling of effort and its lack in attention, — strain appears in expectation, relaxation in realization. Wundt insists that these qualities do not come from the contraction of the muscles and their relaxation, but are as truly affections without assignable sense organs as are pleasantness and unpleasantness. Excitation arises when one is disturbed through attempting a difficult task, is a component of anger and of certain exhilarating forms of joy. Quiescence or inhibition is an accompaniment of rest, perhaps of lassitude. They, too, are peculiar qualities of affection with no sense organs and no definite relations to the other forms of feeling. These extra pairs were supposed to be accompanied by special physical reactions, but later investigators seem to have pretty clear evidence that the experiments in support of them were inaccurate or wrongly interpreted. On the whole, direct observation seems not to bear out Wundt's contention that these forms of consciousness are feelings. There can be no doubt that the states exist, but they seem to be either directly due to special sensations such as the

kinæsthetic impressions, in strain and relaxation, or to more complicated organic processes in excitation and quiescence. These are probably closely related to the qualities of the emotional states to be discussed in the next chapter. In any case they are not affections in the same sense as are pleasantness and unpleasantness.

Affection and the Qualities of Sensation. — It would be highly desirable, were it possible, to give either a catalogue or some general law that should classify the objects or stimuli that give rise to pleasure or displeasure. We have already attempted this for the intensity and duration of stimuli. To list the qualities that are pleasant is much more difficult. Experimental æsthetics has made the attempt in certain fields, but the results are too voluminous to be presented in detail and the general summaries are too few and too schematic to be very satisfactory.

Bodily Accompaniments of Feeling. — While one becomes acquainted with feeling primarily through inner observation or introspection, numerous attempts have been made to obtain some record of the behavior in feeling that may serve as a measure of the amount of feeling, or even as an indication of the nature of feeling. It is a matter of common observation that practically all individuals show pleasure or displeasure by certain physical changes. The face is said to light up or to lower and the general bodily attitude changes in accordance with the feelings. In most cases the presence of pleasure or its opposite can be readily and clearly detected by observation. Many investigations have been undertaken and carried out to translate these simple observations into

more accurate measurements. One of the first series of studies was of the changes in respiration and circulation. The first results seemed to indicate that there was a definite opposition in these processes corresponding to the opposition between pleasantness and unpleasantness. Thus Lehmann [1] asserts that in pleasure respiration is slow and deep, while in unpleasantness, at least after an initial inhibition, it is quick and shallow. The pulse, similarly, is said to be slow and strong in pleasure, and quick and weak in unpleasantness; the blood vessels dilate in pleasure, contract in unpleasantness. Later investigations by Courtier, Shepard, and others make it pretty clear that the effects depend very largely upon the strength of the stimuli rather than upon the affective tone; that all stimuli tend to quicken the respiration and make it shallow, to quicken the pulse and make it feeble and to constrict the blood vessels. It is altogether probable that Lehmann's results with pleasure were due to the fact that pleasant stimuli are usually faint, and so if there has been strong stimulation just before, the vital processes tend to return to normal and thus seem to show changes that are the reverse of the effects of the stimulation. Wundt and his students have attempted to demonstrate peculiar physiological changes of the same sort in connection with his suggested pairs of strain and relaxation, exaltation and depression; but study of their curves indicates that they have been misled by similar phenomena of recovery, and by rhythmic changes that have no relation to the changes in the feeling that they are studying.

[1] Hauptgesetze d. menschlichen Gefühlsleben.

Of the other physiological changes in connection with feeling, the secretion of saliva has been studied most extensively by Pawlow. He found that it was possible to record many of the changes both in feelings and in the intellectual processes of the dog by measuring the flow of saliva. This he accomplished by dissecting out the duct of the salivary gland in the cheek of the dog, and adjusting it so that the saliva might flow into the pan of a recording scale. It was found that the sight of food or of any object associated with food led to an increased flow, and that the amount secreted was a very good indication of the mental state of the dog. This corresponds to the dryness of the mouth in man in displeasure or excitement, particularly in fear, and the free flow of saliva in pleasure even when that be not associated with food. The opposition between pleasantness and unpleasantness does not hold altogether here, again, since any strong excitement, pleasant or unpleasant, gives the same dry mouth. Somewhat the same statement may be made of the secretion of tears. Strong grief or displeasure causes weeping, but the brightness of the eye in pleasure is also due to increased secretion of the lachrymal gland which in extreme pleasure may overtax the tear ducts and flow down the cheek. Slightly better evidence may be given for an opposition in expression in the bodily posture. Grief seems to be marked by a drawing together of all the members, while pleasure leads to an actual physical expansion, — head erect, even thrown back as in laughter, the arms extended and the trunk held straight. These general bodily movements have been much less carefully studied than the others, and the

opposition of the different kinds of feelings shown in superficial observations may disappear when the subject is studied more closely. We may assert, then, that the feelings show very marked bodily accompaniments, but that these cannot be said to correspond accurately to the differences between pleasantness and unpleasantness, although the degree of our feeling carries with it an approximately corresponding amount or intensity in the accompanying physical expression. The expression of the feelings merges gradually into emotional expression, which must form a considerable portion of the matter of the next chapter.

Theories of Feeling. — In attempting to summarize the facts collected concerning feeling and to refer them to a single principle, many theories have been developed. At present the facts cannot be brought to harmonize with any single general statement, but, rather, different groups of facts may be brought to the support of different statements in themselves not altogether consistent. While no single theory may be said to be true to the exclusion of the others, all taken together give a better idea of the nature of feeling and its relations than can be obtained by any mere statement of facts. The first element that is lacking in the construction of a theory is a satisfactory basis in the nervous system. Each of the other fundamental processes has a definite nervous structure or activity to which it may be referred and which gives definiteness to the explanation, but affection has neither special sensory nerves to provide it a particular stimulus, nor special central structures that elaborate its materials. Study of pathological cases of disturbances

of the affective life, such as those that show symptoms of melancholia or euphoria, are accompanied, so far as at present known, by no peculiar lesions with which the diseased affections may be associated or to which they may be referred. So far as changes in the nerve tissue have been traced, they are widespread and general rather than closely localized and specific. It cannot be said that one is pleased or displeased in any particular part of the brain or nervous system, or that affection is carried by any particular nerve or corresponds to any peculiar process.

Physiological Theories. — Of the theories, we may distinguish three main groups with several cross lines of division. One of the oldest and most generally accepted makes pleasure and displeasure the accompaniment and indication of benefit and injury to the organism. This takes different forms, either as an expression of an immediate change in the organism in general, of the nervous system as a whole, or of some particular part of the nervous system. It may be an indication of what has been good or bad for the individual or race in the past and is likely to prove so in the future. For these theories, pleasure means that there is going on in the individual at the moment a process of upbuilding, of anabolism; that this anabolism is induced in the nervous system as a whole or is going on in the frontal lobe, for Wundt the great coördinating centre for all nervous and mental activity. The evidence for each of these theories is indirect and may be found in the general law that the beneficial is on the whole pleasant, that the injurious is on the whole unpleasant. Correspondingly, when one is physically in

good health, well rested and nourished, many activities and even excitations are pleasant that become unpleasant when the physical tone is lower. These facts have been interpreted to mean that action of a well-nourished nervous system or part of the nervous system means pleasure, of a badly nourished means displeasure. Taken literally, the identification of pleasure with anabolism, and displeasure with catabolism, would make all action and stimulation unpleasant, since all action involves use of reserve nutriment. The anabolism-catabolism formula has been modified by permitting catabolism within moderate limits, the limits of ready recuperation, to give pleasure. This point would be difficult to determine empirically, however.

Another change in the statement of the theory permits the formula to mean a general benefit or injury to the race in the evolutionary sense. This enables one to account for many of the seeming discrepancies between benefit and pleasure. Thus, it seems at first not true, even in general, that the pleasant in food or drink is also beneficial. Aside from exceptions we do use feeling as a guide to foods. We eat what we like, or at least we do not eat what we do not like. The exceptions apply to excesses or to substances of rare occurrence in the environment in which the race evolved. The race as a whole is more likely to survive if it makes use of pleasant but injurious foods, such as sweet poisons, than if it ate no sweets. The exceptions must be learned by individual experience. It is much better to eat than not to eat, in spite of the fact that overeating is harmful. When to stop can be learned from the unpleasant symptoms that

indicate injury. Pleasantness and unpleasantness serve as a general guide to conduct, and may be said, metaphorically, to be the expression in the individual of the experience of the race as to what is good or bad. This expression is open to many exceptions, is not a final law, but must be modified by the experience of the individual and the accumulated knowledge of the race. It should be added that how the experience is recorded and transmitted in the individual and how and why it acts are not at all known. The theory is nothing more than a formulation of the general group of facts that, in the long run, what pleases, benefits; what displeases, harms.

Furtherance-Hindrance Theories. — A second group of theories accounts for the more active pleasures largely overlooked in the theories just mentioned. This group couples easy running or unopposed action with pleasure, difficult or opposed action with displeasure. In one form the theory makes real physical movements the basis, in other groups it is taken in a more metaphorical sense. Thus, the first theory states that a smooth, graceful curve is pleasant because the eye will follow it without effort, with a single sweep; while a series of short lines with many changes in direction is ugly because of the difficulty of the eyes in following them. A slight departure toward the metaphorical is seen in the theory of 'empathy' (Einfühlung) of Lipps, in which the individual does not necessarily have opposed action in his own body, but sympathizes with the figure, feels in unpleasantness that he would have difficulty in doing what he personifies the figure as doing. Finally, we have Stout's theory that one may have opposition in the accomplishment of an intel-

lectual purpose, in reaching some conclusion in thought; or, on the contrary, one's mental operations may run smoothly or be helped, and so be pleasant. In each of these cases furtherance or easy action means pleasure, hindrance or interrupted action displeasure. As before, one may accept the general statement, particularly in the metaphorical form, although the more specific applications offer much room for doubt and may be disputed as to facts.

Feelings Dependent upon Earlier Experiences. — The third form of theory attempts an explanation of how feeling can be dependent upon such a wide range of experiences, rather than why one is pleased or displeased. The first form of this theory is Wundt's statement that feeling is the obverse of, or at least one phase of, apperception. For Wundt, apperception is practically synonymous with the active life, covers much of what is treated under attention, perception, and will. It is the effect of the entire earlier experience of the individual in the control of his present action in attending, in interpreting the material offered to perception, in thought, and in practical conduct. This definition makes feeling an expression of the interaction between the coördinated earlier experience of the individual and the present experience. On the nervous side, Wundt gives apperception a seat in the frontal lobe, probably in the front portion of the frontal lobe, and so combines his psychological theory with the physiological in the formula mentioned above, that pleasure corresponds to the action of a well nourished, displeasure to the action of a badly nourished, frontal lobe. This means or may be made to mean

that whether any process is pleasant or unpleasant depends upon the entire accumulated experience of the individual and in the way that experience is brought to bear upon the process in question, a statement that is undoubtedly true, although somewhat vague. If we replace apperception by attention, and consider the nervous factors that are found to play a part in the control of attention, we would have approximately the same formula in our own terms.

We may assert that feeling is an expression of the factors that control attention, an expression of the interaction between the instincts and past experience of the individual, and the present situation; an expression of the reaction of the nervous system of the individual, as the result of original endowment and individual acquirement, to the stimuli of the moment. To give an explanation of pleasantness and unpleasantness this formula would need to consider the essential phases of the other two theories. The theories are mutually complementary rather than exclusive. Thus, the peculiar reaction that gives rise to pleasure is an indication that the stimulus in question has been beneficial; those that give rise to displeasure have been on the whole injurious, either to the race or to the individual. In the one case we deal with an instinctive response, in the other with a response due to individual acquirement. In the individual acquirement, association with similar experiences or direct connection with other experiences, either in themselves unpleasant or pleasant, plays a large part. One may get the affection of the associated experience without having that definitely recalled, as can be seen

in the dislike of many foods with which one has had unpleasant experiences, or a liking for colors that have been connected with some very pleasant occasion. The feeling comes here without necessarily recalling the event that may reasonably be supposed to have occasioned it. Just what the nature of the reaction may be that gives rise to feeling, why we become conscious in feeling of the nature of the forces that are active in controlling attention, we cannot at present say. The justification for the theory is the far-reaching dependence of feelings upon so much of the earlier life of the individual.

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CHAPTER XIV

EMOTION AND TEMPERAMENT

PROBABLY the most impelling and self-asserting mental state in all of the list is emotion. For good or for ill it marks the greatest disturbance in the course of mental events and is the most personal, the most pervasive. Emotions stand in closest connection with feeling and with instinct. From the feelings they can be distinguished only by the amount of response that accompanies them and by their general complexity. Unpleasantness becomes anger or fear when movements of attack or flight begin, when the muscles of the face and of the internal organs grow tense and give rise to sensations. On the other hand, many of the occasions for the emotions and practically all of the movements accompanying emotion are instinctive. Emotion may be defined by virtue of these relationships either as a complicated feeling or the subjective side of the instinct. The list of emotions ordinarily given has varied relatively little since Descartes, and his list can be traced with comparatively few changes to much earlier periods. His list includes surprise, love and hate, desire, pleasure and displeasure; while in Shand, one of the latest writers who has elaborated upon the classification, we find fear, anger, joy, sorrow, disgust, wonder, to which McDougall

adds the more personal qualities of dejection and elation. These are for all authorities the more fundamental emotions. The others develop from them by combination, by change in intensity, in the nature of the object that arouses them, or in the time at which the event that arouses the emotion has occurred or is to occur.

Classifications of the Emotions. — In any discussion of the emotions it is essential to consider separately two factors, the conditions or causes of the emotions and the mental content and physical reaction during the emotion. There are two possible classifications of emotions with reference to cause, although the cause does not necessarily affect the quality of the emotions. Two general causes for emotions have been assigned. One, generally current at present, asserts that emotion is merely an instinct seen from the inside, that the real cause is to be found in the instinctive response. The other, which goes back to remote antiquity, insists that emotions arise from some conflict between ideals or desires and the momentary environment. The first theory applies best to those emotions called out immediately by some external stimulus by virtue of a fundamental characteristic of the organism. Sudden fear at sight of a snake, sudden anger at an injury, the sudden glow of love at first sight, all fall in this class. They need no explanation other than the inherited nervous mechanism.

The second group of theories finds its explanation in the checking of some general movement or current in the life of the individual. In the writings of the older men one finds much difference of opinion as to what it

was that moved, but they agree that all emotions arise from a checking or facilitation of the movement, and also that unpleasant emotions arise from the checking, pleasant emotions from the facilitation. For Descartes the obstruction was suffered by the movements of the fluid products of digestion or the blood; for Spinoza the movement was of an unnamed mental force which was pressing towards a goal of hypothetical perfection. For Shand the impelling force is what he calls sentiment, a force derived in part from instinct, in part from experience, and in part, perhaps, underived, which exhibits systems or groups of forces in ever-widening subordinations. These he divides into the three classes: love, parental sentiment, and the unselfish or social sentiment. When these sentiments find free play or are assisted, pleasant emotions are experienced; when checked or thwarted in any way the emotion is unpleasant. "Every primary impulse . . . when opposed tends to arouse anger; when satisfied, joy; when frustrated, sorrow; and when it anticipates frustration, fear."

The System of Purposes in Emotion. — If one is to accept at all this old theory, obviously the first problem is to determine what it is that gives rise to the determining impulse or sentiment, or, in a more conscious sense, the goal of action. As was seen in an earlier chapter, instinct supplies the impelling force, the directing influence in most conscious processes. To it are due the fundamental tendencies. But upon them is built a great superstructure of desires, acquired from education, through living in a particular environment, that

serves to differentiate the aims of the individual from his fellows, and that characterizes the ideals of the people of one community or social stratum or of one country or of one race. The last two mentioned are dependent in part upon social instincts that make the suggestions and the aims of the group acceptable to the individual. The traits common to all are instinctive; the more particular result from education. Granted that it is instinctive to attain wealth, one must admit that the form that wealth is to take varies from race to race, and the amount aimed at is different for different social groups within the community. Whether one strives for the wampum or cattle of the savage, as opposed to the bank account of modern man, is a question of environment, as is whether one sets one's goal at millions or thousands. Similarly, desire for social approval, for what may be called fame, is general, perhaps instinctive, but whether in athletic skill or scholarship, whether in business or in art, in politics or war, depends upon early environment and even upon chance factors in education. Both the sentiments and impulses of instinctive origin and the ambitions developed at the more conscious stage must be assumed if emotion is to exist. An individual to whom nothing really mattered would be without emotion. The presence of a system of aims makes possible the bare potentiality of emotion; the nature of the aim determines the character of the objects that shall excite the emotions. The emotion itself is an incident in the struggle for the attainment of an end.

The Qualities of Emotion. — While one may distinguish two classes of emotion from the standpoint of

their conditions, no corresponding difference can be discovered in the qualities of emotion. From comparing the qualities of the results, it is impossible to say whether anger has been produced by a sudden swift reaction to an act of brutality towards yourself or another, or whether it is the result of being thwarted in a long-cherished ambition. The exultation over obtaining the means of satisfying a long-continued hunger is no different from the exultation over winning an academic honor. No distinction in quality can be made between emotions, however different may be their conditions or origin. We must turn now to consider the qualities of emotions and to determine upon what the qualities depend.

Recent discussion has revolved more about the qualities of the emotion than the occasions. In its descriptions and explanations it savors much of ancient theories. These had much to say about the part of the body that was active in the emotion and were very full in their descriptions of the accompanying physical states. Thus, Plato assigned courage, ambition, and the nobler emotions to the heart, while lust and the baser passions had their seat below the diaphragm. In common observation one may find the explanation of these references in the sensations derived from the general region of the body in which the movements are felt. The changes in rate of breathing, in the circulation, contractions of the muscles of the chest and abdomen, all are noted by the chance observer and play a large part in the novelist's descriptions of mental states. While the modern author no longer ascribes the emo-

tions to the internal organs in the same sense as did the ancients, he still looks to the organic sensations for the coloring of his emotions; in fact, for a quarter of a century psychologists have been engaged in a controversy as to whether these organic changes did not constitute both the origin and the content of emotion.

James-Lange Theory. — This controversy began with and has revolved about a theory propounded simultaneously by Lange and James. The theory, put briefly, is that the movements of the body when felt are the emotion, and that the mental factors are altogether subordinate. James states it in the apparent paradox that you are sad because you weep rather than weep because you are sad. He enumerates a number of cases in which the emotion comes only after the movements have been felt. One may face a situation with no great appreciation of its danger, even with knowledge that it is not dangerous, and suddenly become aware of a trembling, together with a sinking feeling in the abdomen; with this the emotion of fear is fully established. One may look over a cliff with perfect confidence of safety, and then suddenly have a dizziness and trembling come on that destroys one's self-assurance and even compels one to draw back involuntarily. In these cases action and thought seem to be at variance, and action takes precedence over thought. The theory in general must be accepted as at least a rough statement of certain facts, and this makes it necessary to examine carefully the opposing arguments.

Obviously the problem revolves about the possibility of discovering instances in which emotions disappear

with loss of organic sensations, and instances in which the bodily reactions occur and give rise to emotion when the ordinary conditions of emotion are absent. The first condition was fulfilled by certain hysterical patients who were completely anæsthetic in both internal organs and external muscles. Several of these were questioned in the interests of the theory. The reports agree in general that complete anæsthesia in the parts usually involved in the emotions is accompanied by loss of emotion. One patient, a man who had always been normally emotional, suddenly lost all sensitivity and immediately thereafter became absolutely indifferent to all that passed about him. He parted from his wife, of whom he was very fond, without any feeling of sorrow, and his reactions to experiences that had previously been strongly toned suddenly became neutral or were lacking altogether. While the fact is generally accepted, Sollier[1] has questioned whether the loss of emotion is due to the disappearance of sensation or to the general reduction in the cortical tone in hysteria. Hysterical patients also suffer diminution of all the higher psychical functions, so that it is not at all surprising that their ability to appreciate the experience in a way to arouse emotions should be lost. In this case the failure to have emotions would be due to the intellectual defects or to defects in the higher cortical centres rather than to the mere failure to feel responses.

Almost as contradictory results were obtained from a study of actors who were questioned on the supposi-

[1] Le mecanisme des émotions.

tion that they would provide instances in which the emotion would be felt when the movements were made without any real occasion for the response. A number of famous actors and actresses were asked whether they felt the emotions that they depicted. The answers showed that they were divided into two groups: those who really felt what they were portraying, and a second group who merely carried through their parts as machines. Some asserted that they felt after a performance as if they had actually experienced the events of the play and felt during the performance as keenly as if the scenes were real; the others were perfectly cold. No definite division could be made between the groups on the basis of distinction or success; it seems merely that one group conforms to the demands of the theory, the other does not. James asserts that one must assume that in one group only the external muscles, the muscles of the face and those that give the bodily postures, are affected, while the deeper-lying reactions are lacking. It would seem from this that the sensations essential to the complete emotional experience come from the activity of the internal organs. The others are at least less important.

In any discussion of this theory a sharp line must be drawn between the condition of an emotion and its qualities. James assumes the movements and raises no questions as to how they are excited. He takes them for granted as fundamental reactions of the nervous system. He is content in his detailed discussion to show that the emotion as we feel it is nothing more than the awareness of the bodily state without attempting to say what causes

the reaction itself. He asks only whether anything other than the movements can contribute to the emotional experience. Granting that this in the main must be answered in the affirmative, much remains to be done.

It is to be noted in James' discussion that he does not specify with great accuracy what the movements in any particular emotion may be. He is content to assert that there are movements and to prove that these constitute the quality of the emotion. In this most of his disciples have followed him. They speak much of strains, sinking feelings, and the like, but no single emotion is distinctly described and distinguished from others on the basis of its bodily accompaniments. For attempts at these details one must turn to recent investigations in physiology.

The Sympathetic System in Emotion. — Cannon [1] and his students and Sherrington have made experiments which show what some of the changes are and what part they play in the emotion. Cannon asked two questions: 1. What are the bodily responses in fear, anger, and general excitement? and 2. What is the value of these responses to the organism? For an answer to the first question he looked to demonstrable organic responses. In general, emotions were found to spread through the sympathetic system to practically all of the abdominal organs. Pawlow had shown that the flow of saliva and the secretion of the digestive fluids in the stomach were increased by the taste or odor of pleasant foods, even by sights or sounds that had

[1] Bodily Changes in Pain, Hunger, Fear, and Rage.

been associated with such foods. It has also been shown that pain or the emotions excited in a dog by the sight of a cat or in a cat by the attempted attack of a dog served to check the flow of these secretions even when food was taken into the mouth. These emotions also inhibited the movements of the alimentary canal which usually serve to force the food through it. Some of the effects may be seen in man, in whom vomiting reflexes are caused at times by exceptionally strong emotions, particularly by sorrow and fear, not to mention the slighter reactions always present in disgust.

The Adrenal Gland in Emotion. — Cannon's experiments prove definitely the importance of the emotion upon the secretions of the adrenal gland, a small gland above the kidneys. This gland has been shown to be called into activity by stimulation of the splanchnic nerve, one of the sympathetic system. The gland was also shown to be excited in most of the violent emotions, by pain, anger, fear, and by general excitement. The effects of this secretion are widespread. Briefly enumerated, it serves first to contract the small blood vessels and to increase the ease with which the blood will clot. This action may be illustrated by the use made of it by the physicians in applying adrenin, the substance obtained from the adrenal glands of animals, to stop superficial bleeding. A second action of the glands is to increase the amount of glycogen or so-called blood sugar in the circulation. This seems to be due to the action of the adrenal secretion upon the liver, causing it to release its stores of glycogen and pour them into the blood, whence they are carried to the parts of the

body that may need them. A secondary consequence of these actions is that the effects of fatigue are checked for a time, and the muscles respond with renewed strength. This is due in part to the fact that the constriction of the blood vessels increases the blood pressure and so more thoroughly and quickly washes out the poisonous products of earlier action, and in part to the fact that the glycogen furnishes a quickly assimilated food to the muscle. It could be demonstrated that stimulation of the adrenal glands produced each of these effects, the blood vessels were contracted, the blood pressure increased in consequence, the composition of the blood was changed so that it coagulated more easily, the liver was stimulated to secrete its sugar and, as a result, fatigued muscles were temporarily increased in strength.

These same effects were all produced by pain or strong emotion, provided the adrenal glands were present and connected with the sympathetic system. The increase of blood pressure in emotion is well known and experiments showed that the blood would coagulate more quickly after strong emotion. The increase in the sugar in the blood was demonstrated in cats subjected to pain, or that had been frightened by dogs when no injury could be done them. The same effect is exerted in man. It was found that of twenty-five players on a Harvard football squad twelve had an increased secretion of glycogen, as shown by sugar in the urine, after the contest was over. That this condition was in part due to emotion was shown by the fact that five of the twelve were substitutes who took no part in the game

and that the only excited spectator examined also showed the same reaction. Students examined before and after a difficult and important examination showed presence of glycogen after, but not before, the test.

Looking at the phenomenon as a whole, one may readily see the utility of these reactions in emotions. The strong emotions, particularly the unpleasant emotions, are in animals, and were in primitive man, very likely to be followed by a fight or other violent effort. The animal subject to emotion must usually either fight or run. The bodily changes are a preparation for this effort. The contraction of the blood vessels in the abdomen forces blood into the peripheral vessels and the respiratory tracts, preparing them for greater effort at the expense of the digestive tract, which temporarily ceases its function. The increased glycogen and more rapid circulation under excitement supplies nourishment to the muscles and removes the products of fatigue, thus making them capable of greater activity. The constriction of the arteries and quicker clotting of the blood serve to diminish the hemorrhage in case wounds are received in the conflict. All together, emotion increases the energy of the individual and lessens the liability to injury. It is said in this connection that an artificially induced anger has been used by some individuals to spur them to greater effort.

Identical Reactions for All Emotions. — Cannon concludes from his experiments that all the activities he has studied show the same characteristics for all vigorous emotions, whether pleasant or unpleasant, whether relatively passive as fear or active as anger. All this,

then, must be regarded as having a tendency to disprove the extreme form of the motor theory of emotion, and even to narrow the applicability of the statement that the characteristic qualities of emotion are dependent exclusively upon the bodily response. This theory was also seriously questioned by Sherrington as a result of experiments upon dogs in whom the connection between body and head had been destroyed by sectioning the upper part of the cord. After the operation they showed the same emotional response as before, had the same emotions as inferred from the reactions of the muscles of the head. It was objected that there may have been associations formed between the stimulus to the emotion and the expression of the muscles of the head by the intermediation of the bodily responses, and that these connections remained after the sensations from bodily responses had been cut off. This objection was obviated by repeating the experiments on puppies only three weeks old who had had no chance to form this indirect association. The results in this case were the same as before. Sherrington is convinced that the emotion is the result of cerebral rather than of somatic reactions.

Is Emotional Quality Due to Bodily Response? — If we accept the results of Cannon and Sherrington, it is evidently necessary to ask how much we can retain of the James theory. What Cannon's experiments prove is that there is a large background of physiological reaction and probably a large mass of sensations, common to emotions of all types. In psychological terms one can say that all emotion produces an excitement and that this excitement has a common quality no matter what

the occasion. In this, emotion is not unlike affection in which it was found necessary to give up the old statements that the physiological responses for pleasure and pain were opposed. Now we know that both excite the same changes in circulation, secretion of tears, and of saliva. To this now we may add that they cause the same secretions of adrenalin and the same diminution of the reflexes of the alimentary canal, and that emotions differently aroused are also not to be distinguished in their fundamental physiological effects. The possibility remains that on top of these common elements there may be other responses sufficiently distinctive to constitute the peculiar qualities of the different emotions. An answer to this question requires more detailed investigation than has been given it, for in spite of the long controversy over the James theory, relatively few accurate and extended observations have been recorded of the sensations that come with the emotions.

The Distinguishing Responses of the Emotions. — If we may attempt to supply the lack on the basis of chance observation, statements of novelists, psychologists, and acquaintances, it seems that facial expression, the bodily posture, and a few very general feelings offer the most striking means of differentiation. There are characteristic differences between facial expression in grief and in joy. In the one the lines of the faces are mostly concave downwards, in the other concave upwards. The bodily posture is also different, drooping and contracted in grief, erect and expansive in joy. Of the more internal processes the most evident seem to be an elation in joy and a depression with grief. One

gives a lightness that seems to be localized in the chest, the other a heaviness with its seat in chest or abdomen. No one of these subjective processes has been referred to a definite bodily organ. Strains from the head may be added, but, after all, the list of bodily feelings that can be clearly distinguished is extremely short. Of the specific emotions fear may be distinguished from anger by the general weakness and relaxation of the one and the general consciousness of strength and accompanying activity of the other. Disgust may include sensations of incipient movements of rejection of food either from the mouth or alimentary canal. Wonder, to complete Shand's list of primary emotions, involves relatively slight sensations of strain from the wide open eyes or slightly open mouth, together with the quiescence that comes from the cessation of movement. That these are part only of the movements or sensations involved in any of the emotions considered is at once apparent. That the facial expression and bodily posture are not sufficient in themselves to account for the awareness of emotion is evident from James' evidence that an actor might act a part and not feel the emotion. Careful investigation may be able to go much farther in discovering the movements essential to each emotion. For the present we may content ourselves with the statement that on a background of common responses which furnishes the excitement — an element in each emotion — other reactions occur which possibly are characteristic of each emotion.

The Origin of Emotional Responses. — For the simpler emotions the nature of their responses can be

explained at once as due to the original instinct. As McDougall and others before him put it, the emotion is merely the conscious side of the instinct. When one runs away the observer sees the running with its accompanying pallor and calls it the instinct of flight, while the runner has the emotion of fear. McDougall parallels each of his instincts with an emotion. Disgust accompanies repulsion; wonder, curiosity; anger, pugnacity; elation, self-assertion, in the same way that fear accompanies flight. The explanation of instinct in and of itself is an explanation of emotion. This holds of the larger, more useful responses, but many of the subtler movements are now merely expressive. Even these can be explained directly as the remnants of responses once useful to the preservation of the organism which in many cases have ceased to be useful. They developed as did all instinct by virtue of the survival of the organisms that developed the responses, or by the dying out of organisms that failed to develop them. A large number of the movements can be shown to be direct survivals of such instinctive responses. Running away, drawing back, or the start of fear evidently removes the individual from the neighborhood of the dangerous object. Less obvious is the utility of the trembling and loss of strength that come momentarily in fear. This may be traced to a reduced form of ' playing possum ' or of crouching and remaining motionless as seen in the rabbit and other defenceless animals. It forces them to remain motionless and thus enables them to escape the attention of pursuers and possible enemies. The cry of the child is similarly useful in

attracting attention when it is alone or is uncomfortable. In each of these cases, the conscious state, the emotion proper, is probably of slight value but seems to be an unavoidable accompaniment.

Darwin has suggested that three other classes of emotional expression must be recognized which serve still further to explain or at least to classify the development of emotional responses. These are first, that when an emotion or a condition has given rise to one form of expression, a similar emotion or situation will give rise to a similar response. The second is that, granted an original response, an opposed situation will give rise to the opposite response. His third class is that in which certain emotions result from the direct overflow of nervous excitation without any controlling conditions. The first of these laws is illustrated by the sneer, which Darwin refers to the snarl of the dog. The dog when a possible enemy approaches exposes the teeth and prepares for an attack. In man the situation is similar and probably the mental attitude also. In consequence man, too, draws back the corners of the mouth, although there is now no thought of biting. Similarly, in anger, the nostrils are frequently slightly expanded, although there is now no particular utility in the motion. This Darwin would explain as preparation in the animal for admitting air while the mouth was stopped with the hairy body of the antagonist. The expression continues although the original occasion no longer exists. The second class is more open to objection. The best illustrations are furnished by the movements of a cat in expressing friendliness. When angry, the cat crouches,

keeps the ears back where they will not be in danger of injury, the tail is down and lashing the sides. When pleased, the opposite of this position is taken. She is erect and arches the back, the tail is held high, ears erect. There is no particular reason for this group of responses, and Darwin finds it in the law of antagonism. The mechanism that should lead to this opposed reaction is altogether unknown, and, as we have seen in connection with the feelings and in the recent studies of emotional expression, there is no evidence of a tendency to opposition in the expressions. The third class of direct overflow includes all that cannot be explained under the other heads. Of course it is not really a new head, as all are due to direct overflow of nervous energy, and this third class includes only those that cannot be accounted for at all. Darwin's instances are not very well authenticated. One was of an individual whose hair turned gray over night when he was condemned to die in the morning, reported on the statement from hearsay of an officer from India.

Certain of the emotional accompaniments, in fact many of those that come from the more external and voluntary processes, have taken on a secondary value as a means of communication, as a means of indicating to another the state of mind. The facial expressions directly convey an impression of the emotion and serve as warning or encouragement to the companions to cease or to continue the line of action that they happen to be pursuing at the moment. It is probable that the beginnings of articulate speech are to be found in emotional expression. Many of the lower animals express

emotions through sounds, and it seems possible, even probable, that speech came from the association of some general attitude of the individual making the sound with the sound, and that little by little other associations came to be made with it until our present fully developed languages made their appearance. We can still determine the emotional tone from the modulations of the voice. The loud tones and marked accents of anger, the dragging monotony of the whine of discontent, the softly modulated tones of affection show the emotional state very much more clearly than can any explicit statement in words. They can be detected easily in speech even in a language that we do not at all understand, and convey almost as much of the emotional attitude of the speaker in an unknown language as do words in our own tongue. It is not impossible that these varying cadences were the primary forms of expression and communication and that the words as they developed have been fitted into them.

In the emotions of our second class, due to thwarting or furthering of acquired purposes, the explanation of why the movements should be aroused is not so direct. As was said, the bodily reaction, if one judge from immediate consciousness, is the same as in the other group. Instead, however, of having as the occasion for the reaction some stimulus that has an inherited connection with it, it is aroused by an idea or event that must have become associated with it through experience. Thus, anger or sorrow over the loss of a social honor cannot be said to have a definitely instinctive origin, but the bodily reaction may be little different from

that excited by loss of a dinner and may continue for a much longer time and with greater intensity. Part of this transfer of emotional response from immediately instinctive to more recently developed processes may be explained on the analogy of Darwin's laws. A vague similarity between the more complex and the simpler situation leads to the arousal of the same instinctive responses for both. The social honor is a prize which through the effect of life in the community has become as desirable as a bit of food. When it is lost, the reaction is the same as that which follows the loss of something whose appeal is instinctive. Whatever the mechanism, certain it is that the interrelations of acquired tendencies and their interaction with the environment do lead to responses identical with the purely instinctive. One may add to these the assumption of Dewey that much of the quality of emotions may be due to conflict or coöperation between the habitual responses. These acquired responses might stand to the instinctive responses as the acquired ideals and needs to the innate or instinctive. Possibly the interaction of systems of experience or of neurones might give rise immediately to a conscious quality. If one were to take the result of Sherrington's experiments at full value it would be necessary to assume some such effects and qualities of purely central interactions. Two loopholes in his argument make this conclusion doubtful. His experiments left his pups with a connection between the cortex and the facial muscles, so that the latter might give rise to the emotional content. Secondly, his only evidence of emotion was the facial

expression. Really all that his experiments prove is that one may have the facial expression of an emotion without any connection between the cortex and the trunk or limbs. While much remains to be done upon relating particular emotions to bodily responses, there is every reason to believe that the quality of the emotion, whether it be immediately instinctive in origin or arise from interrelations of purposes and acquired ends, is due in large part to reflex activities. Most of the response is common to all sorts of emotion, but added qualities probably give much of the distinctive tone to the separate emotions.

The Kinds of Emotion. — While the quality of emotion may be accepted as in large part determined by the bodily resonance, the names are not given to emotions on the basis of these qualities. This may be due in part to the large mass of sensations common to all emotions and in part to the fact that emotions are usually named after they have ceased or by an observer if named at all. During the emotion one is too much interested in other things to consider its qualities. In consequence names are usually given on the criteria of the causes of the emotion or of its outcome. Perhaps, too, the fact that fear and anger, love and jealousy, and other emotions are so nearly indistinguishable is to be found partly in the fact that one changes into another with great rapidity. Anger is distinct from fear only in the consciousness of power or weakness toward the intruding man or object, and this changes from moment to moment as the situation is faced. One first fears, then becomes angry, and again is afraid as long as one

is living through the experience. When the situation is properly classified, when it is settled that one is stronger and must fight, or is weaker and must run, the emotion is said to take on a new phase, perhaps even to disappear. If one assume a changing response or perhaps a conflict of responses during the emotional state, it is no wonder that the physical accompaniments of opposed emotions should be identical. Both physically and mentally the two fuse, and one may not be sure, even after the event, whether fear or anger was dominant. This rapid alternation of expressions, taken together with the fact that there are always identical responses in the sympathetic or autonomic system, makes classification in practice difficult and then largely in terms of the intellectual antecedents, the nature of the object, and the outcome of the adventure. It is this that led the popular mind and earlier philosophers to the classification of emotions in other than motor terms.

Relation of Emotion to Other Mental Processes. — Emotions have many and close relations with the other mental processes. In many cases we can trace the development of emotions to the association of ideas. The occasion for the emotion is not infrequently to be found in a recalled event. The reaction in this case is usually not so strong as that made to the original event or sensation, but has many of its characteristic qualities. Often it seems that there is an association between emotional states themselves. After some pleasant emotion the liability to painful response is decreased, while after a disagreeable one, all may tend to

produce a disagreeable emotion. After one success has produced elation every event assumes a roseate hue, — one is easily pleased, the emotion of joy comes of itself. After failure, doubt assails with each new venture. Similarly, after one fright, fear is easily aroused. In short, any intense emotion leaves a predisposition to the same or similar emotions.

Emotion has so many similarities to feeling that one may with difficulty draw the line. Almost all emotions are affectively toned. The exception is to be found in surprise. Külpe would eliminate it from the list of emotions because it lacks affective tone, emphasizing the close relation that he believes to exist between affection and emotion. It is, however, in most of the lists. The similarities between surprise and the other emotions are twofold. First, it is characterized by motor responses, second, by a break in the train of thought or other occupation. Nor is it altogether true that surprise is devoid of affective accompaniments; rather is it to be said that the character of that accompaniment is uncertain. Surprise is in the majority of cases either pleasant or unpleasant, but the same term is used for both pleasant and unpleasant surprises. The differences between feeling and emotion are largely in degree. The affective tone is usually stronger in emotion. As the name implies, the motor responses are more striking and more fully developed. It is generally true, too, that the cause or occasion for the emotion is to be found on the perceptual level, in a stimulus as appreciated, rather than in the bare sensation. No one of these distinctions can be applied without exception, but all

taken together, now one, now another predominating, serve to draw a distinction in practice.

In their relations to voluntary acts emotions have opposed effects, dependent probably upon whether we consider one or the other type of emotions. In those which have an ideational occasion and are to be regarded as interferences with the acquired ends of the individual, the effect of emotion is generally to increase the motor efficiency, at least in the coarser acts. The more primitive emotion, the subjective accompaniment of an intense instinctive response to an external stimulus, is more likely to inhibit voluntary movements, particularly the more refined and accurate movements, although even here the actual strength is increased and the individual is probably more efficient in a fight or in flight. Numerous exceptions may be found to both rules and exceptions. Fear or even anger may leave one practically helpless, with a tremor or weakness that prevents all movement for a time and then probably increases the capacity. Again, slight emotion may enable one to carry through relatively delicate activities, those of an artistic character, *e.g.*, that one might not be capable of in a calm moment.

Emotional Control. — One may control emotions in some degree. The only real control is that effected at the source. The nature and degree of an emotion depend very largely upon the way a situation is classified. An event frequently may be referred to more than one head and will arouse a different emotion under each of these classifications. A human brain, presented to a class with numerous references to what the individ-

ual must have thought with it, and with other remarks that emphasize the personal side, is very likely to arouse intense emotions; but, if considered only in connection with tracts and structure, may excite mere scientific interest. Many of the events of everyday life show the same phenomenon. Classify a remark or the man who makes a remark in one way and you become angry, regard it or him in another light and you are only mildly amused. Much also may be done by preventing expression, although this too can be controlled only by changing the attitude or in directing attention to something else until the occasion for the emotion is past. Either method of control becomes much more effective after practice. Like everything else, attitude and response become habitual; instinctive reactions are changed by habit. The physician or surgeon can look upon patients as cases and neglect the more personal relations. Such professional attitudes are taken by members of nearly all professions with the corresponding development or suppression of emotion and emotional expression.

Summary. — We may think of emotion, then, as a disturbance of the usual or normal course of any succession of thoughts or activities by the intrusion of a new or extraneous event. This event results in a more or less prolonged disturbance of the activities, accompanied by many useless and incoördinated responses, and by intense affection. It is possible to distinguish two types of emotion, or at least two extremes of emotion. One, usually the more violent but usually of short duration, is directly dependent upon instinct, both in

condition and response. This is the type that may be defined as the mental accompaniment of an instinct. The second type, which is usually of slighter intensity and greater duration, is conditioned by the thwarting or furthering of the system of purposes developed by the individual upon an instinctive basis. Even for this class the responses are also of instinctive origin. In this latter case, however, we must look to the mental antecedents rather than to the physical responses as the cause of the emotion, and as the determinant of the type of emotion that shall be induced by any event. The bodily reverberation depends upon the antecedent mental states rather than being itself a first cause and constituting, through the sensations it excites, the entire emotion. This is not to deny the important part played by the movements in giving color to emotion; it merely insists that other factors must be considered in discussing its origin.

Sentiment. — Sentiment is ordinarily used to designate the milder, more lasting forms of emotion. Shand has varied the application of the term to indicate the antecedent condition of emotions, the system of impulses that dominates the individual, which, when furthered or hindered, gives rise to the emotion. The sentiments are for him dependent upon the instincts, but the instincts are in turn modified and developed by experience. The two great systems are love and hate. These are fundamental, constitute the impelling forces of all activity, and give rise to emotion when acted upon by particular events. When aroused they are or may be directed toward particular persons or objects. They

approach the particular emotion rather than the fundamental tendencies which constitute the background, the impelling force needed for the development of emotion. This definition emphasizes the characteristic of duration implied in the usual meaning of the word and has been accepted by McDougall and Stout. There is no doubt also that there is need for some name to designate the systems of impulses or purposes, but some word implying greater force would be better than sentiment, since these systems are the forces behind all voluntary activities, mental and physical, as well as the occasions for the emotions. What is designated is more like what is usually called desire or a system of desires than sentiment. While the authority behind this definition of the word entitles it to respect, sentiment seems better suited to designate the mild continued emotion, its more usual meaning.

Mood and Passion. — Mood is a predisposition to an emotion of comparatively short duration. It may be due to physical causes. Lack of sleep, a fit of indigestion, and many other indispositions predispose to unpleasant emotions, while good health and rest conduce to pleasant emotions or sentiments. Moods, too, develop from earlier emotions. A disagreeable emotion, as was said above, leaves a tendency to other unpleasant emotions, and this is a mood. Moods, then, are rather dispositions to emotions than any particular kind of consciousness or behavior of themselves. Passion, like sentiment, has been used in various ways at different times and by different men, now being extended to cover the entire field of pleasant and unpleasant acts or men-

tal states, and again restricted to the more violent exhibitions of the emotional reaction. At present it can hardly be said to have any technical meaning. As in the popular sense, it most frequently designates the more violent forms of emotion.

Temperament. — Temperament is a word with a long pedigree in psychological usage and one that has undergone little change in application since first introduced. Galen recognized four humors in the body, blood, phlegm, black bile, and yellow bile, and assumed that the disposition of the individual was largely determined by the one that was dominant. These gave rise to four principal temperaments, the sanguine, the melancholic, choleric, and phlegmatic. These names still persist, although they have taken on slightly different forms at the hands of different psychologists and in the popular mind. Thus Wundt makes the temperaments depend upon combinations of rate and strength of response in a given individual. The sanguine is said to be quick and weak, the choleric, quick and strong, the melancholic, slow and strong, the phlegmatic, slow and weak. This corresponds to certain of the characteristics of the terms as popularly used, but omits what seems the most important, the tendency to pleasant or to unpleasant emotions. On the whole, the schematism of Wundt has little to recommend it over the looser application of the terms in popular speech. All together it can hardly be said that we know more about temperaments than that individuals differ in their susceptibility to the different emotions. At present there is no complete classification of these dispositions. The ideal of

Galen, that one might group individuals in such a way that it would be possible to determine what mental and physical capacities and dispositions were necessarily associated and find some simple test that would determine to which of these classes each individual belonged, is almost as remote to-day as it was when Galen wrote.

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CHAPTER XV

THE GENERAL PRINCIPLES OF ACTION — WILL

The final outcome of all thought, of all mental processes whatsoever, is action. In connection with the nervous system it was seen that all stimulations tend to find an outlet through the motor nerves and muscles, and movements play an important part in almost all mental states. Movements accompany all acts of attending, and several authorities explain the fact of attention itself by the movements called out, rather than by the antecedent mental states. In perception, movements are used as a means of explaining space, time, and rhythm; recognition is, for some authorities, merely a revival of old movements. We find many writers who explain many if not all of the essentials of the reasoning processes in terms of movement. Either as beginning, intermediate stage, or end of every mental state we find that action has an important place in fact or theory.

We may assume in our present chapter that action is the real aim of life, and that most of the operations so far discussed are preliminary to it. This action may follow immediately upon them or may be delayed for a considerable period. Here, however, we are more concerned to see how the other processes lead to action, than to

understand the part that movement plays in them. In the first place, we may assert with some confidence, on the basis of practically universal agreement of the psychologists of to-day, that there are no new forces, nor even any absolutely new laws involved in the control of action. All mental states give rise to movements of greater or less extent, and, on the other hand, movement as a psychological process can be explained only in terms of certain mental states already discussed. Were we to give a complete explanation of movement, we should have a review of each of the preceding chapters with an appendix on the way in which movement resulted from it. We can at most add the appendix in this chapter. Assuming that the fundamental principle of all action is that all excitations tend to pass over from the sensory to the motor neurones, we may raise several fundamental questions in connection with this process which may be discussed or put aside now before we proceed to the details.

Sensation and Movement. — One of the most important is whether the sensory excitation that leads to movement must be accompanied by sensation. The evident answer is that sensation may or may not accompany the process. Some assert that normally all movement comes from sensation, but we have also the opposite view that all sensation is aroused by the excitation of the motor neurone or even by the movement itself. Neither of these extreme views need concern us here. We may be content with the statement that the excitation of motor processes certainly often takes place with no accompanying sensation, and that all that is really

necessary for the movement is the previous excitation of some sensory organ or sensory neurone. This latter may come through some indirect path involving a memory, or the cortical cells ordinarily active in memory. The natural thing is for the sensory process to discharge into movement. What really needs explanation is why at times the sensory excitations do not cause movements. In the complete sense they probably never fail to arouse some response, but it is frequently too slight to be noticed. The fundamental fact of action in general needs no special explanation.

Is Conscious or Unconscious Action Primary? — Another question that has been much discussed is whether conscious or unconscious action comes first. It has been argued by Titchener, Cope, and others that the original actions, the action of the lowest animal forms, were all conscious, that they had sensations fully developed as the occasion of the action, and were conscious of the results of the action and lost that consciousness with use. The other theory places the unconscious reflex act first and makes consciousness appear at some higher stage. Each is dependent upon indirect arguments. The holders of the first theory give as evidence the fact that in man many movements, once fully conscious, lapse through repetition into automatic acts, or acts that have no conscious accompaniments, and assert that the development of movement in the race must have run the same course. The other view rests upon the assumption that evolution, in action as in other processes, passes from the simple to the complex, and that the reflex is the simplest form of action. The

only difficulty lies in the impossibility of saying where in the course of animal development the conscious form of movement might have made its appearance. There seems to be no point from the simplest organism to man where one can say with full assurance that action takes a completely new form. Since we have no evidence as to whether the lowest forms are or are not conscious, and in man no evidence that first movements are really the outcome of conscious processes, it is simpler to assume that reflexes are the original movements and to keep the question of the presence of consciousness as much in the background as possible. We shall find that even in man the relation of consciousness to action offers many unsolved problems.

The Methods of Learning. — Starting with the single assumption that movements always follow upon, and are the outcome of, sensory stimulations, the first question that meets us is what it is that determines what movement shall follow upon any given stimulation. We have seen that certain connections are present in the organism at birth, the result of the heredity and evolution of the individual and of the species. These innately determined movements are the reflexes and instincts. The greater number of movements in man and in the higher animals are found to be the outcome of learning, to be due to connections formed after the birth of the individual. The problem of how these connections are formed is one that may be said to have found its answer within the last twenty years in the studies of animals.

The experiments were begun by Thorndike, who tested

the methods by which a cat learned to escape from a box that had a door fastened by a simple catch, a button that could be turned, or a bolt that might be drawn by pulling a string hanging down inside the box. To make sure that the cat would make an effort, it was hungry when put into the box and food was in sight on the outside. The process of learning has been found

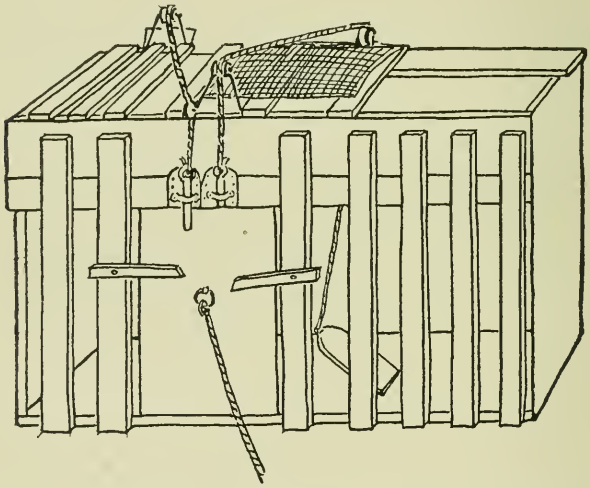

FIG. 90. — Animal problem box. (From Thorndike, "Animal Intelligence.")

to depend in practically all animals upon the presence of random movements, — is one of trial and error. The cat makes a large number of movements of all sorts, tries to force herself through all promising openings, bites at all projections, scratches, and mews; in fact, she exhausts all the acts, reflex, instinctive, and habitual, that she has at her command. Sooner or later one presents itself that happens to open the door. She

scratches at the button and by pure chance turns it. When the door is open she walks out. But one successful movement does not teach her the method of opening the door. When put in again, she goes through a series of random movements a second time, and again will hit upon the correct response by chance. It is only after a number of successes — how many varies with the intelligence of the animal — that the right movement will be begun at once when the animal is put into the box. Each trial will, on the average, require less time than the one that preceded it, but there are many variations owing to chance difficulties.

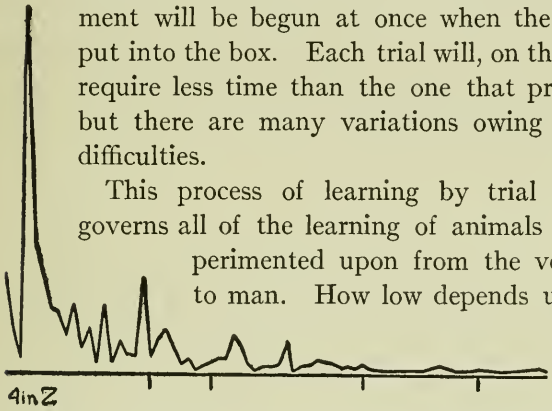

FIG. 91. — Curve of learning in dogs. Height shows time required for hitting upon each correct response. (From Thorndike.)

This process of learning by trial and error governs all of the learning of animals so far experimented upon from the very lowest to man. How low depends upon what is meant by learning. In the early chapters it was noted that Jennings found that movements were modified by the results of earlier actions even in the unicellular organisms. The Stentor, *e.g.*, would, when slightly stimulated, at first bend to one side and then later give up all responses. If the stimuli were made more intense, it would first bend away sharply and then, after several responses which failed to remove it from the excitation, would release its hold and swim away. This, the most rudimentary form of learning, is never-

theless learning. From that point on, more and more complex movements may be acquired as the organism increases in complexity. The essentials of the learning process in animals seem to be that any problem must be solved by chance at first; that, after the right movements have been hit upon a sufficient number of times, a connection is established between a certain stimulus or group of stimuli and the movement in such a way that the stimulus tends at once to call out the corresponding movement.

This still leaves open the question as to what brought the so-called chance response in the first place. If we turn back to the nervous system, it may be said that a given sensory impression stimulates a sensory neurone, which in its turn has axones connected with a number of motor neurones. The synapse to one of the motor neurones probably offers least resistance and the impulse passes across that. If the result which comes from the act gives pain or does not remove the unpleasant stimulus, a new set of responses will be started as the stimulus becomes strong enough to open less permeable synapses. If, *e.g.*, the cat does not escape, get the meat, and in consequence begin the instinctive responses involved in eating, then new synapses will be opened and other movements result until some change in the stimulation starts a new series of responses. It should be remembered that there is not one stimulus but many, and that, as attention changes, new stimuli come which also make possible new movements. When the movement has been made, the same stimulus will produce the same movement, and each repetition reduces

the resistance at the synapse as in the formation of association. In animals and in the ordinary learning of man, each movement is the result of instinctive responses or of earlier habits. Watson asserts that there is no real formation of new connections in learning, but that all is due to the elimination of certain of the unnecessary movements in the first trials. His theory is that the inherited connections usually offer roundabout paths between stimulus and movement. This series of responses is innate. Trial and error finally make a more direct connection between the stimulus and the successful act. On this theory learning could never lead to absolutely new connections. It could only shorten the course. Undoubtedly a large part of learning is of this character.

How Far are New Connections Formed in Learning? — In man, however, there seem to be cases in which there is no natural nervous connection at the synapses, or at least in which the instinctive connection is very weak and in which learning takes place through a spread of impulses over synapses very slightly permeable. Thus, in learning to move the ears in the experiments that Bair carried out, a connection was formed, a path of discharge was opened to a muscle not ordinarily under voluntary control. Here there seemed to be a gradual spread of impulse from the usual channels to more and more unusual ones, until finally it chanced to find the old path to the *retrahens* muscle, the muscle that pulls the ear back. Then repetition stamped in the connection until it could be repeated at will. Another case of the formation of new connections is furnished by the surgical

operation that replaces an impaired nerve by another with an altogether different central connection. Thus, when there has been paralysis of the nerve innervating the flexor muscle of the arm, it has been possible to divide the nerve supplying the extensor muscle and connect one part of it with the injured flexor muscle. When it has regenerated, the nerves that previously produced extension of the arm now carry the impulses which produce flexion. Here evidently we cannot be dealing with a dropping out of old connections but must have the formation of altogether new ones. It would seem, too, that the movements established after recovery from infantile paralysis must be due to the transmission of impulses over new paths and hence are the result of forming new connections between sensory and motor neurones. All three of these involve formation of connections that are not definitely present at birth; in the second instance, in fact, they follow paths and produce movements the reverse of those that are innate. Indeed, much evidence is accumulating that there is considerable variation in the paths followed during the same function of the cortex. If confirmed, this fact would prove that the formation of new connections is the rule rather than the exception.

The Acquisition of Skill. — In the adult man the most important practical problem of learning is how series of acts, already under control in isolation, may be united into a single series, may be made to constitute a unitary group. This is what happens when one acquires skill in any game or occupation. A number of investigations have been carried out on problems of

this sort. Bryan and Harter investigated the learning of the telegraphic language; Swift, typewriting, toss-

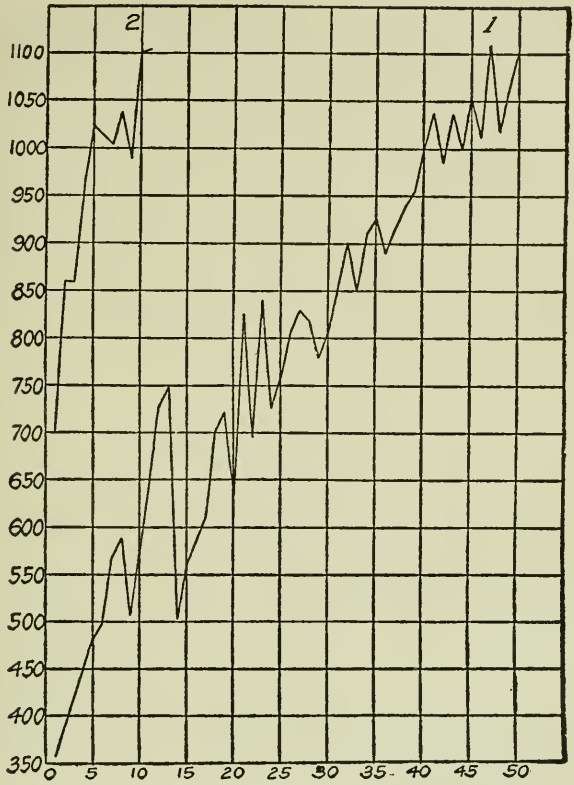

FIG. 92. — Curve of learning to write on the typewriter. The horizontal distances show the number of days of practice; the vertical, the number of words written in an hour. Curve 1 shows the progress during the original practice; curve 2, the results of nine days' practice after an interval of two years and thirty-five days. (From Swift.)

ing balls, and learning Russian; Bair and Book, typewriting. All obtained the same general result that

skill comes rapidly at first and then more slowly, and that in the course of the work there are many periods in which no progress is made, followed by periods of rapid improvement. In each of these tasks the individual movements are known in advance. One can press the key of a telegraph instrument or of the typewriter or toss a ball at the start. What is necessary is to organize the whole so that one element shall start the next, and all shall be carried on together without false movements, and as rapidly as is possible. All agree that improvement here, like the original learning, comes largely by chance successes. One hits upon some more effective combination of movements without any definite foresight, and even without knowing what it was that caused the improvement. The worker does his best all along, and at times an improvement comes, at times it does not. There is always fluctuation from day to day. This seems due in part to the general physical condition, in part to chance changes in the character of the work. The preliminary feeling offers little or no indication of what the course of the work is to be. One may feel well, even feel certain that a good score is to be made on a certain day, and find that the accomplishment is lower than on days when the general feeling seems to offer less hope of success.

Plateaus in Learning. — One of the most interesting questions is why there should be the long periods of no progress, the so-called plateaus. They have been reported by all observers and are present in most of the curves. The same amount of effort is made, and all the conditions seem to be approximately the same, but

no progress results for a long period. Various explanations are given for them. Bryan and Harter assert that they are periods in which the old associations or partial habits are being more firmly implanted, and that this is essential for any further advance. In certain cases this seems true. It has also been asserted that they are periods in which the worker loses interest and relaxes effort, but most workers do not accept this as a general explanation. They are also found when effort is kept at a maximum. Granted that the plateaus are necessary as preparation for a new advance, the reason for the advance to a new level offers difficulties. Three explanations have been suggested. (1) The simplest is that the preparation has been completed and then some new combination of movements is hit upon that makes the progress possible. (2) Even Bryan, who argues for the preparation as the explanation of the plateau, insists that there is often at least some special stimulus. He quotes instances of telegraphers who have spent some time in a small office showing a sudden rise in ability when transferred to a main line office. Here increase is probably the result of new incentives. (3) A third factor that plays a part is becoming clearly aware of the conditions of the problem, of what must be done to gain full control, — with that there is frequently an increase of skill. Effort may play a part or may not according to the time at which it is exerted. If all is ready, increased effort may give increased effectiveness; if the effort comes too soon, it may be a detriment and even lead to postponement of the advance.

Batson has recently carried out an investigation of the learning process for tossing balls. His conclusion is that the plateaus are the expression of the time taken to associate several movements into a chain where several separate movements must be combined into a unit before new progress is possible. Thus, keeping two balls in the air with one hand requires three separate acts, estimation of direction, estimation of the right height to throw the balls or of the force, and estimation of the time required for the balls to rise and fall, since the ball is seen only at its highest point. Unless these three acts could be made together, no real progress was possible. The plateaus were thought to correspond to the periods during which the three factors were being combined, or during which each was being learned separately before they could be combined. If the act to be learned was simple, involved only one process, no plateaus were found. If attention was distributed over the entire process, if one included all three part processes in attention at all times, the plateaus were not so likely to appear. In Batson's experiments they appeared only in composite acts where the parts were attended to separately and then joined into groups. Whether this explanation will hold for all problems can be determined only when others have been analyzed into their parts in a similar way. We may content ourselves here with the statement that acquiring skill in complex acts is, like learning in the simpler forms, due to chance trial and error, a process in which the learner does not know how he makes advances either before or after they are made. The associations are

formed through frequent repetition, and the plateaus, or stages of no progress, are periods when associations necessary to new progress are being formed. The rise comes through some chance new combination, due to some new incentive, to an understanding of the conditions of the advance, or merely when the preliminary connections have been sufficiently thoroughly developed.

Learning by Imitation. — A suggestion that may deserve a moment's notice is that one may learn by imitation. In one sense this is of course very largely true. We tend to imitate the more striking acts of those in whom we are interested and with whom we come into contact. But at most this acts as a goal toward which one may strive by a process of trial and error, rather than as an immediate cause of the action. That there is no fundamental impulse to imitate is evident from experiments made with animals. Thorndike found that when one cat was permitted to watch another get out of a cage a number of times, the time it required to make the same movements was not noticeably shortened. Similar results have been obtained by various other investigators under approximately the same conditions. In his work, referred to above, Bair found that even compelling the muscle to make the movement to be learned by stimulating it by an induction current did not decrease the time required. The impulse must develop from the cue or stimulus to be used to incite the movement, if learning is to take place. To be helped serves at most to direct attention to the right movement, but to make it, if it be not already learned, requires the usual process of trial and error. The same statement

may be made of the effect of imitation in more complex acts that are already at command. The sight of another making them serves to give the idea, and that may, if desired, lead to the act. What force it has is due to the general social instincts, rather than to any specific instinct or impulse to imitate.

Consciousness and Movement. — When one attempts to determine the factors that precede and control movements already learned, to ask why the movement is made and how it is controlled, one comes upon rather more difference of opinion. We have already seen that all movement follows upon stimulation. These stimulations all go back in last analysis to sensory excitation. In most of the more elaborate acts of human adults, some consciousness accompanies this excitation, and in a very large number of cases the excitation that precedes is from the activity of a memory tract rather than from the stimulation of a sense organ directly. Each of these factors introduces certain complications, raises questions that must be discussed. One of the first is what does consciousness add to the process and is it necessary that consciousness should be present? Here opinions differ. Consciousness does accompany many if not most acts when they are first made. On the other hand, before an act has been definitely learned, consciousness of what is to be done seems, as has been said, to help very little in the learning; after it has been learned, consciousness becomes more and more indefinite until finally it may completely disappear. In view of these facts it seems difficult to do more than insist on the importance of the sensory innervation as universally

present. The degree of consciousness and what its effect upon movement is may be left an open question, and its presence need be pointed out only where what is conscious gives a definite explanation of the characteristics of the act.

The Incentives to Movement. — We may divide the conscious accompaniments of movements into three groups. First, the initiating processes; secondly, the directly sensory processes; third, the awareness of the result. These must be considered separately. What the initiating process may be has been much discussed and many suggestions have been made concerning it. Probably all have been too definite. Thus, several have inclined to the view that movement must be preceded by the kinæsthetic sensation that arises when the movement is made. To speak a word one must recall the sensations made when that word has been uttered at some earlier time, or to move the hand to cut the leaf of a book one is reading, one must recall the sensations felt when that movement was made. Woodworth has shown that these sensations are seldom present, and a little observation will indicate that you do not ordinarily have them in mind before the movement is made. More frequently present are visual images, but even these are not always definite. If you decide to rise and walk across the room, you will see that all that is necessary is to notice a book and remember that you must read something in it before you go on. With a very general idea and the sight of the book, the movement begins and is carried to its conclusion. Even visual images are not always present. This

is too obvious to mention in the case of speech, which is influenced more by auditory images. In most cases the imagery that precedes, whose presence may be regarded as constituting the intention to move, is very schematic and almost anything in any way related to the act may serve as the incentive to movement.

Meaning as an Incentive.—In this, action is very little different from thought. In fact, Woodworth first came to his hypothesis of imageless thought through a study of the mental content that precedes action. As in thinking, our memories and ideas are brought into systematic groups, in which any one element may serve to represent any other, so the antecedents of acts are also grouped and the act results from the appearance of any element of the system. Organization is as evident in the control of action as in the control of thought. Just as an idea which is not at all similar to an object may represent that object, so an idea or sensation that has been only indirectly associated with a movement may come to represent that movement and in fact constitute the intention to make it. In practice one finds that almost any idea or impression that has been connected with an act may be the immediate predecessor of that act. Any mental process may constitute the incentive to any act with which it has been closely associated, just as any image may have any idea with which it has been associated as its meaning. Colloquial language connects the two and uses the single word for both. 'I mean to do that' is a common expression as the equivalent of 'I intend to do that' and the use of the term is justified by psychological analysis. A meaning, using

the terms in the technical sense of the earlier chapters, may quite as naturally have an issue in movement as stop short in the mere representation of an idea.

Different Types of Antecedents of Movements. — Three distinct classes of mental processes may be discovered among the antecedents of action. The most common is the intention or the meaning, a representation in some form of the goal or result of the act. This goal may be represented as a concrete sensation, as a very general notion, or may have no appreciable imagery, or at least no appreciated imagery. It may take any of the forms of a concept. The initiating idea for a stroke at golf may be a definite image of the point where the ball is to land, it may be some vague verbal thought that it is well to land near the tree on this hole, or it may be that the stroke is guided by nothing more definite than the assumption that the next stroke is in that general direction, an assumption that is not formulated but is due to the appreciation of a particular step in the game. It must be said that this third stage is very rare in a game of skill, but much more frequent in partially automatized tasks. At times, intention is lacking or much in the background, and a sensation or idea closely associated with the movement serves as the incentive. This may be either the kinæsthetic image mentioned above, or it may be the sight of an object, as when a spot on the tablecloth catches the eye, and the finger moves towards it even to the later embarrassment of guest and hostess. The second cue is different from the first in that it does not correspond to a purpose, or may be directly opposed to the general purpose. Finally,

some sensory stimulus may cause a movement that is altogether unrelated to the intention of the moment.

Interaction of Incentives. — These three different sorts of antecedents may oppose and disturb each other in the control of the resulting movement. The intention is the most frequent antecedent but, if at any point in carrying out the intention an extraneous idea be permitted to become dominant in consciousness, it disturbs or prevents the movement. Thus, if one is making a golf stroke and suddenly permits the ditch immediately in front to catch attention, the ball goes into the ditch in spite of the good general intentions of the player. In a baseball game, in the same way, if some object other than the point at which the ball should be thrown is attended to, a bad play is fairly certain to result. Even the attachment of a *not* to an idea does not always prevent it from affecting the act. Langfeld found that in experiments which consisted in moving a wire along a groove, endeavoring to avoid touching the sides, the experimenters were more likely to touch the edge if he asked them not to touch it than if he told them to keep the wire in the middle of the groove. Attention to the side induced a movement toward it in spite of the intention to avoid it. Within limits, trying not to do a thing has the same effect as trying to do it. This is particularly true in acts of skill and of movements only partly learned. It is true in general that an intention of the more remote sort is frequently conquered by an idea of a specific movement, even if that be directly contrary to the intention. The same holds of the third type of antecedent, a sensation not directly connected with the

movement. A sudden stimulus that comes in the course of an attempt to make a difficult movement will frequently disturb or destroy it. A sudden loud noise or bright light spoils a delicate line with the pen or the aim of a rifle or a drive at golf. Not the meaning alone but that, together with the idea or object that holds attention or the sensory stimulus that forces its way into consciousness, serves to direct the movement.

The Control of Movements. — The second of the three groups of conscious states accompanying movement is the sensations aroused by the movement. These also play an important part in directing the act. Movement is in this respect much like memory or reasoning or the process of learning. The incentive must be distinguished from the control; the attempt, from the recognition of success or failure, together with the correction that goes with the latter. In addition to the sensory processes that initiate the movement, the accompanying sensations exercise a constant guidance. These are divided by James into two classes, the resident and remote sensations. The resident are the kinæsthetic sensations. The remote are the sensations from eye or ear that indicate where the moving member is or what the sound is that is being produced. Both of these sensations or groups of sensations ordinarily control the movement without being directly noticed. As a finger is moved with the eyes closed, the kinæsthetic sensations are constantly coming to the cortex and sending out reflexes that serve properly to direct the movement to graduate its force and extent. They are most easily demonstrated by their absence. In tabes the

motor nerves are unimpaired, but the posterior columns in the cord which carry the kinæsthetic sensations are destroyed. A characteristic symptom of the disease is inability to control the movements. When the eyes are closed, the patient is not able to bring thumb and finger together accurately and still less to bring two fingers together in front of the face with a single sweep. Locomotor ataxia with its irregular gait is one form of the disease.

Remote Sensations. — The remote sensations are also active in detecting and correcting any departures from the intended course of action. Thus, when writing, if the hand starts to make a crooked line, it is at once seen and the eye directs it back to the right position. The influence of the eye is not appreciated but, if one attempts to write with the eyes closed, it is at once apparent that an important correcting force is lacking. The ear acts in the same way in governing speech, and the tone in singing. Experiments show that most singers, some of them among the most famous, are not able to strike the correct tone at once, but make an attempt, are quick to detect that the tone is too high or too low, and so adjust the pitch to the correct one. The violinist, too, does not estimate the position of his fingers on the string by the kinæsthetic sensations, an estimation that would require marvellous accuracy, but approximates the position first, and then, as the bow begins to give the tone, he adjusts the length of the string until his ear tells him that the tone is correct. That the remote sensation is essential is shown by the fact that the deaf cannot speak without special train-

ing. This seems to supply the control that the ear cannot give by kinæsthetic and tactual sensations. The deaf child feels the teacher's vocal organs and keeps trying until he makes his own carry out the same movements. The sameness of movement is at first recognized by touch, but with practice the kinæsthetic sensations may be substituted. These control processes also become automatic, so that one notices neither the sensations themselves nor the fact that they exercise control. The sensations from the eye guide the hand reflexly, or with as little thought as is required for the reflex.

Another striking case of reflex guidance of this sort is that exerted by the static sense, the stimuli from the vestibular branch of the auditory nerve. This, as was seen in the earlier chapters, makes close connections with the motor centres in the brain stem, particularly with the cerebellum and the roots of the motor oculi nerves. These sensory nerves probably give no sensations, but nevertheless they guide the movements of the body as a whole, serve to keep the balance, give rise to compensatory eye movements, — movements that keep the eyes fixed on the same point in spite of the movements of the head and body. The sensory impulse calls out these movements continuously and with no knowledge that the movement has been made, certainly with no appreciation of the fact that they are producing the movements. The stream of impulses coming in through the vestibular nerves constitutes an important element in the forces that control any movement.

Any act, then, may be said to be the outcome of the appreciation of a situation that requires movement. The immediate incentive is usually some object or idea that for the moment holds the centre of attention. But this incentive is nearly always not the picture of the movement to be made; it is more frequently some idea of the end to be accomplished. If the movement is relatively unfamiliar, it is an idea of some immediate act; if very familiar, it is usually the remote end that is held in mind. The intention does no more than mean the movement; it seldom recalls it in sensory terms. Always the movement is guided by the resident and remote sensations. These adjust it to the conditions of the moment. When a movement has been repeated sufficiently often to become automatic, attention is needed only at the beginning. The act is started, and attention then turns to something else; the association between the movements and the resident and remote sensations serves to carry it to its goal. Thus, in walking on a familiar course, one merely decides to go to a certain place and, when once started, one step starts the next, always under the control of the remote and resident sensations. The visual stimuli lead to the avoidance of obstacles, guide in making the necessary turns and, unless some new obstacle is encountered, one may go into a brown study at the moment of starting and not realize again what is going on about until the destination has been reached. All movements or chains of movements, at first learned or joined together by effort and under the influence of a complete consciousness, tend gradually to lose more

and more of the conscious accompaniments and antecedents. Finally, in more complex acts, they may start from some unnoticed stimulus; in the case of simple acts or a number of unified simple movements, they may be started by a single idea, may be initiated by a conscious process and guided to their end by habit without further consciousness. Associations between the movements themselves or between the resident sensations of one movement and the motor processes required for the next take the place of all more definite awareness. Even in these automatic acts, there is guidance by a wide group of habitual connections between neurones, not at all appreciated by the agent.

Choice and Motives. — We have been assuming all through that the intention to make a movement has been present, but a process antecedent to the intention requires discussion. This is the problem of choice. It is true that most acts are automatic or habitual, that the decision was determined long before the time the act is to be performed, and, when the occasion presents itself, is carried out immediately. But in occasional instances two opposed acts are felt to be possible, and it is necessary to choose which is to be made. The actual act of choice is relatively simple. It is constituted in giving one intention free play and in checking the others. The actual mental content consists in attending to the movement to be made or the result to be attained. When the choice or decision is made long before it is to be carried into effect, it consists frequently in outlining the course of action in words or in some idea, — some concept perhaps. When

the time comes, the stimuli present lead at once to the act. The only new problem in connection with choice is what leads to the intention, why one course is chosen rather than any other. This goes back to the determination of the selection of one or the other end, or of one or another of the possible sensations that are present in consciousness. In either case the explanation lies finally in the laws of attention and association, and offers little that is new. The deciding factors are subjective, those that have been seen to be the conditions of attention and of association. One seldom regards as choice the decision determined by objective factors alone.

Mental Attitude in Control of Choice. — The influence of the situation and the mental setting or context have been frequently mentioned above. It was brought out in a slightly different form by Ach [1] in a long investigation of the conditions of choice by means of the reaction experiment. First he asked his subjects to move the right finger when a letter *E* was shown, and the left when the letter *O*. The times required for making each movement were measured. It was found that there was no real decision made after the cards were shown, but that the movements were made at once because of the previous preparation. When the subject was left free to react with either finger, it was found that more time was taken than when the finger to be moved was prescribed. These facts may be regarded as indicating that the first form of reaction gives play to choice, while the others were determined by the conditions of the experiment, the purpose of the moment.

[1] Ueber die Willenstätigkeit und das Denken.

It was in these same experiments that the control of the arithmetical associations was studied. The same results were obtained. When two numbers were shown one above the other and the observer was told in advance to add or subtract, the result came at once or after a relatively short time. When, on the other hand, the numbers were shown with no instructions, the resulting process was much delayed, and the observer had a chance to study the process of choice. This task or purpose serves to control choice just as it does to determine association. The effect of the purpose is replaced by the situation and the general intentions of the moment in many choices of everyday life. It is this that leads one to take an umbrella when the sky is cloudy and a cane when it is clear as one goes past the rack in the hall, to choose a serious volume when one comes into the study in working hours and a novel or the newspaper in the period just after dinner. In all these things the choice, while apparently undetermined, is guided by the general attitude and the environment.

More Remote Influences in Choice. — In more complicated and important instances of choice, the final selection is similarly determined, but the controlling influences are much more numerous. The final release comes with thinking of the end to be accomplished with the full belief that the act is to be carried out. The antecedent processes are much like the balancing of decisions in doubt before full belief presents itself. One thinks first of one alternative, then of the other. After these alternations have repeated themselves several times, one finally dominates, is held in mind,

and the others are by that very fact excluded; the decision is made. The forces that favor the possible alternatives are to be found in the instincts on the one side and the social forces on the other. They constitute what are called the motives. The motives are themselves pretty well out of consciousness ordinarily. One knows only that one course of action or another is preferable but has no knowledge why it is preferred. Carrying this back, we see that of the possible lines of conduct the one is chosen which proves most attractive. Why it is attractive is determined by natural endowment and education. There is no trace of what is ordinarily called will.

Is there a Peculiar Will Element? — A problem much discussed since the beginning of psychological theory is whether there is a specific quality or a specific function, apart from those outlined above, which can be called the will. The earlier writers, always tending to discover a separate faculty or force for each of the words in common use, hardly questioned the existence of something of the kind, something which was an actual force in decisions and an incentive to action. As the direct examination of mental states began to take the place of speculation with only inaccurate observation, fewer and fewer men were able to discover this peculiar state. Instead, an ever-increasing number of authorities found the final cause of action in an idea that was attended to, in an idea of movement with the belief that it was to take place, or in the feeling qualities preceding or accompanying the idea. The more work done upon the analysis of the consciousness preceding

action, the less there was found that was peculiar to this state.

Recently two investigators, Ach and Michotte and his followers, have revived the old doctrine in a slightly new form. In certain of his more complicated reaction time experiments, Ach asserts that it is not merely holding the idea of the movement in the centre of consciousness, but that in addition to this it is necessary that the self becomes momentarily identified with the movement to be made. At the moment the self is thus identified with the one alternative, the choice is made, the action is determined. A somewhat similar statement is made by Michotte in connection with a choice between operations upon numbers as a result of experiments carried on by himself and Prüm.[1] In a second experiment, also on reaction times, conducted with Barrett,[2] measurements were made of the time between being offered two liquids, and choosing and swallowing one of them. The liquids represented different degrees of pleasantness and unpleasantness. They were tested in advance and designated by letters that should have no associations other than those which developed during the experiment. The observer was to watch carefully what preceded the decision and to determine if possible what was the deciding factor in his choice. In this series of experiments the element of voluntary choice seemed to play a smaller part. In fact, Barrett regards

[1] Michotte and Prüm, Étude expérimentale sur le choix volontaire et ses antécédentes immediats, Archives de psychologie, vol. x, p. 113.

[2] Barrett, Motivation Tracts and Motivation Forces.

the result as proof that choice is made and executed without any peculiar new activity that could be designated an act of volition. Instead, he found that one arranged the tastes as they were learned in order of agreeableness, and, when they were presented, the value on this scale was an immediate guide to the choice. The whole choice was completed when the liquid had been given its letter and place in the series. He finds that the determinants of the act are approximately the same as those we have enumerated above. Michotte[1] in reply reasserts his belief in a pure act of volition which must intervene in all acts of choice, whether related to action or not, and after the choice is made must again intervene in the execution of the act involved in the choice. He believes that the selection of one from a group of liquids of known value tends to render the process more automatic and that this accounts for the smaller part played by voluntary choice.

This difference of opinion between Barrett and Michotte is typical of the opposing possibilities in the explanation of a voluntary act. On the one hand, emphasis is placed upon the more remote underlying conditions; on the other, upon the necessity for discriminating between the alternatives by holding in mind, first one of the motives, and then the other, and making a positive choice between them. On Barrett's interpretation, the motives are effective because they appeal to certain instinctive or habitual and social traits in the man's nature. On Michotte's, the final

[1] Michotte, À propos de contributions récentes à la psychologie de la volonté, Ann. de L'Institute Super. de Phil., No. ix.

determinant of action is a force or active element which serves to make the choice and release the act. On the second alternative, the active element is hard to describe, is found by only a few men and by them only on rare occasions. Popularly, it plays a large part in discussions, but the observation by the untrained men upon which it rests is faulty and much of the feeling of will which it observes is made up of strain sensations, which even Michotte would not regard as an essential part of his voluntary act. Viewed from the practical side, it makes very little difference whether this active element is or is not assumed. All would agree that when will acts, it acts in the light of the motives; it is an expression of the nature of the man, and that in turn is dependent upon his instincts and training, his immediate purposes and general ideals. The only question remaining is whether these act directly in the execution of the movement, or whether they act first upon the will and that in turn determines the act. In consideration of the uncertainty as to whether the will activity exists and what it is like if it exists, it seems more simple and safer to omit it as superfluous, and to assume that the observed conditions determine action directly. On that conclusion, 'will' is a term to designate the whole man active, or a word used to distinguish between the acts that imply choice and are controlled by the system of purposes as opposed to the automatic acts, not a word to designate any new and distinct entity.

The Will and Freedom.— This result suggests the old problem of the freedom of the will, and it may be considered here, in spite of the fact that it is at present

regarded as belonging to ethics rather than to psychology. At first sight it seems a logical inference that, if man has no will, it cannot be free. This defines the will too narrowly; it would restrict it to the something that we could not find standing between the motives and the act itself. If we regard the will as the sum of the conditions which lead to action or to spontaneous action, or even more generally as the whole man active, the question cannot be disposed of so summarily. From this point of view, the answer as to whether the man is free depends very largely upon how we define 'the man.' We have seen throughout that many of the determinants of all mental action, and particularly of voluntary action, are to be found in his instincts, in the way he has been affected by education and by the society in which he has lived, by his nature and nurture in the broadest use of both terms. If one is to oppose these external forces to the man himself, a good case could be made for the statement that the man is largely determined by forces outside of himself. But if one make the division between the man and all of these factors, if one take away from the man all that he has learned, all the controlling forces of society, and all of his natural endowments, his instincts and innate tendencies, only a rag of a man would be left; most that is peculiarly himself would have disappeared. It is altogether more satisfactory and truer to the facts to regard these influences as included in the man, to think of him as in part at least the product of his heredity and environment, for this is the man as we know him. To attempt to divide the controlling forces into two

groups, one external, the other internal, one environmental, the other personal, has never been attempted, and no two men agree where the division would come. Oppose the man as he is to external forces and he must be said to control his own acts. They are the expression of the whole man, and he is free to do as he chooses. One may put the solution of the problem in another way by asserting that man is free to do what he desires, but his desires are the outcome of his instincts and environment and over these he has little control. In other words, the question is largely one of classifying facts and of defining terms. The facts themselves are largely accepted by all.

In practice, acceptance of one theory or the other makes little difference. What one generally does is to think of one's self as a free agent in every respect and of every one else as rigidly determined by environment and education. It is only when one takes the objective attitude toward one's own acts, that one tries to trace them to their conditions. Probably this assumption works best in practice. The new tendency to regard man as the product of his environment has led to the improvement in social conditions, to the recognition that mankind in the mass may be improved if one will but begin with remedying the fundamental conditions of living, that changing his environment is better than talking to him. Improvements in education, in housing conditions, and all the multitude of laws for bettering the environment of the poor, are due to the growing tendency to regard the environment as responsible for the actions of others. On the other hand, the

belief in one's own freedom probably gives added initiative, and increased recognition of individual responsibility that would be lost were one to think of one's self as a mere link in the world chain. However, the instinct of self-assertion is too strongly embedded to permit acceptance of any theory to change the aggressive individual into an inert one.

Probably the difference in the attitude towards crime and the criminal more clearly represents the effects of the two theories. On the older, free-will doctrine, the criminal was altogether responsible for his acts. He would or he would not carry out each act. There could be no control of crime, because no one could tell when an individual might decide to commit one. The other theory looks upon the criminal as the product of his heredity and of his environment, in much the same way that a sick man is the victim of circumstances. In the extreme form, the whole problem is one of removing the causes of the crime, as the control of health is one of removing the causes of disease. The attitude toward punishment changes similarly. If the man is free to be a criminal or not to be, the only value of punishment is to get even, to measure the crime and make him suffer as he has made others suffer, ' an eye for an eye.' On the other theory, punishment is merely a means of reform. It gives the criminal a motive for refraining from crime, it may give him a chance to form new habits, or even to learn some new trade or obtain some other means of support that shall make crime unnecessary. In the worst cases, it is a protection to society by removing the criminal to a place where he can do no harm.

In any case the idea of vengeance, essential to the older view, plays no part. When it is considered that a large percentage of criminals are mentally deficient, have an intelligence no greater than a child of ten, the modern theory has even more weight. The final outcome of the two theories is approximately the same, but the methods of inflicting the punishment and the attitude while carrying it out are altogether different. On the whole it may be said that the problem of the freedom of the will has been outgrown rather than solved. The present attitude toward the world and man's place in the world leaves no room for the problem, rather than deciding which solution is the correct one.

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CHAPTER XVI

THE SELF

In our ordinary life and in much of scientific psychological discussion frequent use is made of the term self. For popular thought the most important part of consciousness and of the world as a whole is found in the ' I.' To it practically everything is referred. It is regarded as the effective agent in most of the acts of the individual, and is the source of most of his emotions. A notion that has so large a share in our mental life must be closely examined and if possible explained. We must, as psychologists, take the same attitude toward it as toward the concrete experiences so far examined. We must seek to determine how far it is open to examination as a mental state, what effect it has on behavior, and how the idea must have developed to the form that it takes at present. It is for us one phenomenon among many, in spite of the central position that it takes in popular discussion. The occasion for the development of the self comes from the practical needs for a distinction between the individual and others, and between the individual and the outside world. To represent these distinctions concepts have gradually grown up in much the same way that concepts of external things develop, and are like them in every respect. Each has some

mental content and means a large number of distinctions and processes not present in the idea.

The Occasions for the Self-concepts. — There is not one concept of the self but many, corresponding to the different occasions, to the different ways, in which the outer must be opposed to the inner, and to the different lines of division at which one may be marked off from the other. Three fairly general lines of demarcation may be drawn. One is between the man as a whole, including the body, and the other individuals in society. This is the self as considered in law and in most of the more popular objective discussions. A second line of division develops, as the theoretical interests become dominant, between the body and the mental states or consciousness. Finally, a third notion of the self tends to mark off the more spontaneous and purposive acts, those that are foreseen and consented to, as over against the acts induced by external forces or even by reflexes, — the acts that are intended, from those that are not intended. The first we may call the physical self, the second the subjective self, the third the effective self. It must be insisted that these lines of division cannot be sharply drawn and that they are not consistent from moment to moment. At any particular time we are interested only in one distinction and have no reference to the others. While there are many gross references and many occasions on which it is desirable to unite the three concepts into a single one, they can best be discussed separately at first, and then united so far as is possible in a common notion. In considering these concepts, one must, as in all cases, distinguish between

the conscious element used in representing the self, and the meaning, — the thing or processes represented by that concept.

The Physical Self. — The centre of reference of the physical self seems to be the body, partly as it is seen in the field of vision, partly as it is reconstructed on the basis of mirror images and photographs and from the references of friends. The meaning of this physical self is very much wider. It is used to refer to the body, together with many of the man's immediate possessions, — garments and adornments and an ever-widening group of properties. The physical self gradually comes to be indistinguishable from the physically mine. Houses and lands, friends and position, all of the things that one must struggle with the others to retain, come to form part of the physical 'me.' This physical self derives much of its meaning from comparison with others. One tends to see one's self in relation to others about. The man's picture of himself and of his possessions always involves a comparison with others and with the ideals that these set for his own attainment. The wealth of the individual rich and poor alike has increased enormously in the last century, but nevertheless the line is quite as sharply drawn now as ever before, since the relative differences are approximately the same. Similarly, one's opinion of one's physical self in the narrowest sense varies with the individuals with whom one comes in contact. One feels one's self quite a man among small men, while there is a decided shrinking when with men of large stature. One can imagine how different Gulliver's impression of himself must have been when in Lilliput from what it

was among the Brobdignagians. This first concept represents the man to himself as a man among men. It is the self in the most practical popular sense.

The Subjective Self. — The second concept that represents the self as opposed to the body is of much less general application, is of value in fact only in connection with more theoretical problems. The imaginal centre of the concept is less definite; probably kinæsthetic and organic sensations offer what little there is of actual content. Sometimes there may be a picture of the self as the spirit of the savage, or the ghost of the ignorant, a bodily self with the physical characteristics subtracted, so far as that is possible. This seems relatively rare among psychologists, and others have not reported their results in sufficient numbers to afford much ground for generalization. Usually one is satisfied with the sensations of strain in the head or in the chest as an embodiment of the notion of the self. Its applications, too, are relatively few. One pictures one's self as rising above bodily limitations in ill health; one opposes this to the sense organs and their imperfect reports of the world. In psychology it is made to include consciousness as opposed to the activities of the nervous system which are purely mechanical. It is also of value in explaining dreams, in which the body seems to be in one place while the spirit is in another. When we attempt to determine to what place sensations are ascribed, there is little agreement even for a single sense. The skin marks the boundary of the self for touch; one thinks of one's self as receiving impressions at the surface and not at some point back in the brain. For hearing

and sight the line of division is not so definite. Most refer the sensations to the object in the outside world, and the hearing and seeing self is given no definite place. Organic sensations, particularly the strain sensations that come with effort, are assigned to the self as opposed to the body. On the sensory side, then, while every one would assert that mind and body are to be distinguished and that the 'I' is on the self side, the line of division is very vague. In most cases one would deny any of the seats that might be suggested for the processes without being able to assign a better. It would not even be matter of agreement whether the self in this sense included all of consciousness, or, if not, exactly how much it did include. Obviously, this second concept corresponds to a real need in psychological discussions, but equally obviously the concept is not at present and probably cannot be very clear cut, either in its image or in the limits that it makes between self and not-self.

The Active Self. — The third concept of the effective or dynamic self represents a more real need both in psychology and in practical life. In nearly every one of the processes we have considered, there has been something left unsettled in the explanation. The final presupposition upon which explanation of each was based had many similar elements in each of the processes discussed, and different theories sought an explanation of each of the more important processes in some other. In attention, first, it was seen that there was a final factor which was characterized by the feeling of effort reduced in part to sensations of strain, the condition of which was found in social pressure. The resulting

attention was classed as voluntary. The same factors were at work in the control of associations and were later seen to be factors which, when present, increased the rate at which associations were formed. In the emotions it was found necessary to assume some tendency toward an end, some purpose that must be aided or hindered before emotions could appear. Finally, in action it is necessary and usual to distinguish simpler movements that come under the head of reflex, instinct, or habit from those that seem to depend upon wider knowledge and more fully conscious purpose. In each of these there is something in common. Voluntary attention was explained by the social instinct; emotion seemed dependent upon purposive activity of some sort; action is commonly explained by attention to an idea or an end. Nor is the interrelation limited by these statements. Many authorities would explain movement in terms of feeling; others, feeling in terms of movement; still others, attention in terms of movement; others again attention in terms of feeling, just as feeling and movement are explained by some in terms of attention. The common elements in all of these processes and the last term in the explanation of each are often called the ' self.'

The self in this sense has practically no new mental processes to represent it. One may think of it as the physical self or a ghostly self. The only sensational element that is at all a general concomitant is the mass of strain sensations so frequently mentioned as constituting the feeling of effort. These are taken to serve as an indication of activity rather than as a direct revelation

of the self. In the attempt to analyze the factors which determine the course of this activity, we again have little to say. Our first reduction to social pressure proves, when seen in the light of our knowledge of instinct, to reduce largely to a social instinct guided by knowledge obtained from the society in which the man has lived. The original instinct we found in discussing emotions developed into a system of ideals, and these, as they became more active, constituted the purposes of the individual. The study of action offered no new contributions to our explanation; action was an outcome of ideals and purposes acting in selection. There was found no new impelling force, nor even any new quality or mental state. Study of the self adds nothing new. As a man studies his own self, he is aware of the fact that he is acting or deciding, but he gets almost no light as to what the process consists in. If he studies another, he can trace certain factors that seem to play a part in making that individual decide as he does, but neither observation of one's self nor of another can show directly what the determining activity is. Curiously enough, tracing the conditions tends to discover the basis of the activities that are believed to be peculiarly characteristic of the self in society. The more intimately personal the act, the more objective are its conditions, the more external the forces that bring it about.

In each of these more active processes, one feels that there is something that must be explained in terms of factors that cannot be definitely formulated. The tendency is always to bring in some other simple process as the basis of the explanation, hence the reference from

one process to another among mental states. But, when one sees that one can complete the circle and come no nearer the explanation in one group than in any other, it is obvious that going around the circle has not furthered the explanation. Two alternatives remain open. One may assume either some highest process as an explanation of all the others, or that there are common elements in each, and seek to determine what they are. The popular mind takes the first of the alternatives, — assumes the self as a prime determinant and makes that the final force in all spontaneous action. Since, however, this is in reality no explanation but merely a tagging of the facts that are to be explained, it is more important to determine the elements common to each. This we may find in the developed ideals and purposes, which in turn are to be referred, first to instincts, then to the ideals of society taken over by the individual largely by virtue of the social instinct — the instinct to seek approval — and then tested and confirmed by his own individual experience. If other factors play a part, they cannot be traced, either in the introspection of the agent, or by a study of the behavior of others. In the complexity of the conditions that act upon the individual we are not, however, in a position to assert that no others are effective at any point.

The Social Factors in the Self Concept. — These three concepts of the self tend to fuse into a single one in which something of each is retained, and are more or less harmonized into a unitary whole. The representative self has something of the body, something of the mental as opposed to the bodily, more of the strain processes

that mark it as active. The concept is ordinarily employed to distinguish between the self and society, between the 'I' and the 'You,' or, objectively, between the characteristics of the different individuals with whom one comes in contact, who must be used in the accomplishment of one's ends, or who use you in the attainment of theirs. With this there is a marked effect of the life in society. Both the static and the dynamic features of the self are appreciated only in terms of others about. One has an idea of one's own peculiarities only in comparison with others. One's notion of one's self as a whole is largely an image of the self as it is reflected in the consciousness of others. When a man is among men of smaller attainments, or smaller possessions, he expands; when he is with men of larger accomplishments or reputation or possessions, he shrinks just as evidently. Much of this idea of the self depends, not upon actual ability and possession, but upon the imagined attitude of others. A man becomes accustomed to act as if he were of more than ordinary importance, society takes him at face value, and he may go for years or even through life without having the notion corrected either for himself or for others. On the other hand, a few rebuffs to a sensitive individual will repress his self in his own eyes and prevent any self-assertion. If he has high ability, it may go for years without being discovered. Society makes its judgment of a man in part from his own actions, and these in turn depend in some measure upon the estimate he thinks society puts upon him. The process is a circular one. The individual's estimate of himself is what he believes

to be society's estimate of him. On the other hand, society's estimate of the man is very largely colored by his estimate of himself and his consequent bearing. The way in which the individual pictures himself and the estimate of his personal capacity are largely derived from the attitude of society toward him, just as many of the forces that control his active life are merely an expression of the society in which he lives.

The Emotions of Self. — The activities and processes that develop the notion of self are found very largely in the emotional group. What we called the more complicated emotions, those which come from the interaction of the purposes of the individual with the environment, are largely social in character. The opposition is largely from other men, and the emotion is usually ascribed to an expanding or shrinking of the self. In fact, in much of our daily life the only reason for making use of the notion of the self is to picture the origin and the immediate source of the emotion. We are concerned with the self only in moments of struggle and the consequent success or defeat. In periods of quiet contemplation of external objects or even in the unhindered manipulation of things, we are little aware of the self. With opposition, particularly from other men, the complex of emotions comes into play. We have the self-assertion of effort, the elation of victory, the self-depreciation of defeat. That these emotions are always of a social character is seen in the fact that when one performs a difficult feat when alone, there is always a thought of what some one else might think, and the pleasure in the success comes largely from the background of realization

that it is better than could have been done by the rival. The onlooker is always present in thought if not in reality, and the resultant emotion is determined by the way the action would be viewed by him rather than by any absolute standard.

These self-regarding emotions constitute the core of the idea of the self. The character of these emotions seems to depend upon the relation between the ambitions of the individual and his actual accomplishments. James puts it in the statement that self-esteem equals success divided by pretensions. When pretensions are large, success small, self-esteem is slight; as success grows or ambitions diminish, self-esteem or self-complacency is increased. Self-esteem, too, is only affected when success or failure comes in some field in which the ambition of the individual lies. A scholar may very well content himself with little of the worldly goods, may even regard wealth as somewhat vulgar, since he has never set himself towards its attainment. The wealthy man of affairs returns the compliment by saying he can buy the services of a scientist much more cheaply than he can the advice of a financial expert, — that learning is a drug in the market. Each is satisfied with his own position, with his own self, as he has never attempted to extend the self in the field of the other. But when men of affairs come into rivalry in the same field, the self of the one is humiliated as the other attains what he has himself sought.

These emotions, or the conditions that lie behind them, not merely determine how the individual shall regard himself, but also play a very large part in deciding the

degree of effectiveness of the individual. The way in which the self is regarded determines the attitude toward the problems of life, and this in turn is an important factor in the success or failure of the individual. The character of the individual, viewed either from within or from without, is closely related to his self-esteem.

The man who has succeeded and lacks a sense of proportion or the saving sense of humor becomes self-conceited. He can no longer remove his mental gaze from contemplation of his own capacities and of past successes, nor can avoid expressing this appreciation of himself nor conceal his expectation that others will express their appreciation of that position. A child who is always the centre of the approving household develops an exaggerated notion of his own importance, and his early success in business or scholarship not infrequently sets an attitude of self-satisfaction that cannot be disturbed even by later failures and rebuffs.

More striking is the expectation of failure and consequent lowering of ambitions that comes with crushing defeat. A man of middle age who suddenly finds his system of ambitions thwarted and all of the accumulations of previous successes swept away, seems to lose not merely all of his ambitions, all of his self-respect, but also the capacity for forming new purposes. The self disappears or is profoundly altered with the despair that follows. Numerous members of the drifting colonies of ne'er-do-wells of our large cities have been brought to their position by some such catastrophe. The man of means who has been confident, self-assertive, and persistent loses his wealth through some mischance, fails in

the first few efforts to reëstablish himself, and then mistrusts himself and all his ventures,—becomes vacillating. Others lose confidence in him, and he either decides that nothing is worth while, takes a care-free attitude toward the world and attempts nothing, or falls into despair and, while his ambitions are retained, he gives over hope of realizing them. In brief, the system of ends feeds on success and grows as each ambition is realized, but shrinks and finally disappears with repeated failure. Happy is the man whose ambitions are not too different from his capacities and to whom environment is sufficiently favorable to permit the realization of ambitions in sufficient degree to give constant encouragement, without too great expansion of the notion of his capacity and importance.

The self is in this sense an outcome of the emotions which originate when the system of aims receives a shock or attains one of the subordinate steps toward an end or the end itself, and the emotions are in many cases referred to the self as the cause. At bottom, the two processes are probably one. The self is a concept that serves to explain both the emotions that originate from the progress toward ends and also the purposes themselves. Here again we seem to be going around in a circle. Where we seek the self, we find only expressions, only processes that have needed a self to explain them, rather than a real self. On the other hand, when we seek the explanation of certain of the more fundamental emotions, we are said to discover evidence of the self, or at least a reference to the self. In other words, wherever we seek the self, we find something else, but whenever we

are seeking an explanation of spontaneous or purposive action, we find that we need, or at least wish we might have, a self.

To bring together the results of our investigation, the self is a group of concepts originally developed to represent the different lines of division between the man and others, between the mental and physical processes, and between the more mechanical and the more spontaneous forms of action. The different concepts are frequently fused, at least in part, into a single concept which becomes representative of the system of purposes as they control actions, which gives rise to emotions and serves to designate the directing forces in the more complicated mental processes. This concept is the point of reference for all our self-regarding ambitions, it is the self we are depressed about and the self that we exult over. Nevertheless it must not be assumed that something corresponding to this self need be found by introspection. Just as space, regarded as a concept, was needed to explain certain of the ways in which we saw objects and the possibilities of movement, so the concept of the self is merely a way we have of representing to ourselves the immediate facts found in the emotional and the active life, in the life of decision. Examination gives us nothing more than does contemplation. We can analyze the way in which we perceive space relations into certain elements, we can show why we need the concept of space, but we do not expect to find anything more by any means. Similarly with the self, we can point to certain strains as usually present when we think ' I,' we can show why it is needed as a means of making certain

distinctions, but we should not expect to find anything more by observation or experiment, — and we do not.

Self-identity. — Extensions of this empirically derived self-concept or other related concepts have been developed to solve certain of the more theoretical problems of psychology and metaphysics. One of the simplest of these is to answer the question of how the continuous, ever-changing series of mental processes should all be referred to the same self, are held together in a continuous stream, and are regarded as states of the perceiving self. As a matter of fact, the practical man is never bothered by this problem. In observation he is concerned only with the things that are meant. It is only in recognition that the fact that he has seen a thing before plays an important part, and even then he is more interested in knowing that the object was in a certain place at a certain time than with the fact that he saw it there. The different experiences are held together as parts of a single whole by the interrelations that make recognition possible, that make it possible to refer each experience to a definite position in the series. This fact of reference is immediately observed. When the self-concept has developed, the theorist makes that the point of reference, in spite of the difficulty in seeing how an actual substantial something apart from the experiences could hold them together. If by the self we mean the experiences themselves as interrelated one to the other, the notion offers less difficulty.

The Unity of Consciousness. — Similar theories have suggested that the fact that all of the mental states form a unity at any moment can be explained in terms of

the self-concept. Again it must be insisted that what is or can be noticed is the unity, so far as that exists, rather than an 'ego.' A self in addition to the states would not give them unity. Rather must the unity come from the interconnection of mental states, the subordination of all to some single one that is the central point of attention. As has been seen frequently, many processes, some corresponding only to partially aroused association paths, coöperate in constituting any single experience. In part this unity is explained by the nervous system in which many neurones are always aroused together and the action of each produces a spread of impulses to all of the others; in part it is to be referred to the interrelation of what might be regarded as single elements in the formation of concepts and meanings, the real mental units. In any case the unity is within the mental states, not a unity that comes from without through a connection with some single thing. In both of these cases, as in the more empirical active and emotional processes, the facts are to be found in the continuity and unity of mental processes; the self-concept is developed or introduced to explain them. It is merely a method of picturing, not an actual experience. Here the concept is even less satisfactory as an explanation than it was in the preceding instances.

In one respect the more cognitive processes which are explained by this more passive type of self may be combined with the more active discussed above. The system of purposes which was seen to be the deciding factor in deliberate action and to determine the character

of the emotions is closely bound up with the system of knowledge. Given the instinctive basis, each experience modifies that instinct and gives it definite content at the same time that it aids in the construction of our system of concepts and prepares the way for recognition and for meaning. In this way the two groups of systems become closely interwoven and are for the most part probably merely different expressions of the same fundamental unity. When active in the control of perception and reason, we term the result the cognitive processes; when acts and emotions are involved, we speak of purposes. All education influences each, if in different degrees. The system of purposes closely determines the acquisition of knowledge and the use made of it in memory and reasoning, while the knowledge obtained has its effects on the formation of purposes. It is the close interrelation and dynamic interaction of all parts of experience that really give a unitary character to the acts of the individual, determine his intellectual interests, and make possible the continuity of recognition and of meaning.

Dissociations of Personality. — That this interrelation of all parts probably has a physical basis is evident from the fact that in certain abnormal individuals each of these processes may be broken up into two or several systems, each of which acts alone to produce all the capacities of a whole individual, but which differ in the characteristics of each of the partial personalities. The cases of alternating or dissociated personality offer much of dramatic interest, which cannot be treated here. A person who may be in fair health will suddenly

find himself in a strange situation, with no memory of anything that has happened before. In one case even the most rudimentary knowledge of simple things was lost, and some days were required for the patient to recognize simple objects, and still longer to learn to speak. For a long time this second set of experiences remained cut off from the old, then finally the patient awoke again with no memory for recent events, as if he had just waked up into the first set of experiences. In most cases the second self comes into being with a portion of the original memories and experiences of the old. There is a dissociation of the old into two or more parts, rather than a development of an entirely new series. The patient suddenly wakes in an unfamiliar environment, with no memories of where he may be or of recent events, but with full command of language and the ability to interpret the objects about. After that the different personalities or groups of experiences will alternate. The time occupied by one self varies greatly, as does the occasion for the change from one to another.

Characteristics of the Partial Selves. — If we relate the characteristics in which the selves vary and the marks that distinguish them one from the other, to the facts that have led to the development of the self-concepts, we find that practically all of them may be closely paralleled. One element in the consciousness of self is the persistence of various organic sensations. One feels at home in the body, if we may indulge in metaphor, because the strain sensations are constant from one time to another. Ribot reports some cases of split personality in which the organic sensations were changed,

and suggests that the change might in part have accounted for the alteration. Much more important is the break in the line of association, the inability to recall an event in one state which has occurred in another. The train of memories seems to be broken off sharply when the personality alternates. Everything that happened in one state can be recalled in that state, but all the experiences of the other state are lost. There is also no recognition in one state of the objects seen in another. The associations that connected them originally are completely broken while the associations within each group persist. It is this characteristic that gives the name of dissociated personality. In the dissociation there seem to be peculiar divisions of the original self. In the Beauchamp case, reported by Dr. Prince, one self kept the knowledge of French of the original, while the others were entirely without it, and other acquirements seemed to be assigned to one alone of the personalities.

Not merely are the acquirements differently divided, but the active and emotional characteristics seem also to vary. One self will be highly conventional in action and desires, will respond very quickly to social intincts, the other will be entirely arbitrary in action. The difference may approach that so vividly pictured by Stevenson in his story of Dr. Jekyll and Mr. Hyde. The purposes of the two selves are different as well as the memories. This is in accordance with our explanation of the development of ideals by the action of the accumulated experiences. When the systems of knowledge divide, the control exerted by each of the two sets of ideals or purposes is exerted differently according to the com-

ponents that make it up. Dr. Prince suggests that in certain cases the instincts as well seem to be divided. One self will take most of the tender and benevolent instincts, the other most of the aggressive, the rebellious, antisocial instincts. Where one self will be painfully conscientious and considerate of others, the second will be altogether selfish and indifferent to the ordinary family and social welfare. With the break in knowledge, there goes a corresponding sudden alternation in the effective self. The individual shows different emotions, is differently controlled in action and in thought. Aside from the fact that both selves are still in the same body, they are essentially two individuals, two selves. There is no memory or recognition of events that occur to the other self, there is no consistency of action between them, there is no continuous self-consciousness from one to the other. Both the theoretical and practical characteristics of the two selves are altered.

Dissociation. — If we attempt an explanation from the physical side, it would seem that the various effects upon the nervous system are retained and organized into systems; that these systems, while ordinarily acting as units, may by certain shocks be dissociated along somewhat definite lines of cleavage that also develop as a result of the formation of distinct systems. When the break comes, we have each system or group of systems persisting, but with no bonds of connections between them. Each system continues to act alone and to control the responses through the persistent nervous connections, guided by the wider series of partially active neurones. In most cases certain of the more frequent

nervous activities are common to the two systems, but this shows itself only in the persistence of the nervous correlates of more general concepts and ideas, to which each of the new experiences may be referred and be understood, with none of the more specific references that constitute recognition. The normal self has as its correlate on the physical side a complete system or system of systems, from all of the more important parts of which impulses might pass to awaken all of the other parts, — a system that embraces and unifies many lesser systems, all of which are connected. So long as this system remains unbroken, memory is continuous, memories from all parts of the life may be recognized and the actions are sufficiently controlled to be consistent. That this is the basis for the characteristics that we have regarded as constituting the peculiar condition of the self is evident from the fact that, when this complete system is broken into two or more groups of systems, two or more selves make their appearance.

Hypnotism and Other Forms of Dissociation. — Not only does dissociation arise spontaneously, but in many individuals it may be induced at will. If, for example, a patient be asked to keep attention continuously fixed upon some one object, he will pass into a cataleptic stage, his muscles will stiffen, and he will gradually to all appearances become unconscious, and in the higher degrees of the resulting abnormal condition will show many of the phases of the dissociated personality. The state is much more readily induced if the patient remains passive and is told from time to time that he is losing consciousness. When most completely hypnotized,

the patient is highly suggestible, will do anything that he is told to do, may even be made to take on different personalities. On waking there is ordinarily no memory of what has happened during the hypnotic state, although when hypnotized again, the person may recall the events of this period. The close relation between this and the phenomena of the dissociated self is indicated by the fact that change from one self to the other often can be induced by suggestion in the hypnotized state and that when hypnotized in one state, that self will recall events experienced in other states. In many diseased conditions there is evidence that partial dissociation of these systems may take place and may be responsible for the disease. Hysteria is largely, if not altogether, due to a breaking away from the whole of some one of the systems. This may not be large enough seriously to disturb the higher coördinations of the self, but does prevent the larger system from receiving impressions from certain sense organs connected with the dissociated elements and may also cause a paralysis of the muscles that are either permanently or temporarily united with those dissociated elements.

Consciousness and Subconsciousness. — Numerous theories have suggested that the self is seldom completely united, that there are always larger or smaller groups of experiences or memories which are independent of the larger system. Thus, Freud at present explains dreams and many of the accidents of daily life as well as the witty sayings of the normal individual by the fact that he has an organized complex of elements, which usually contributes little to consciousness but which on occasion

will be excited and when aroused open new possibilities for good or evil in the individual. This detached complex is frequently said to have all of the elements of the normal or total self, to have desires of its own, to do thinking for itself, — in fact, to constitute a true self, which is also regarded as being conscious. Many facts point to the presence of these complexes, and the assertion that a definite consciousness attaches to them raises many questions as to what our ordinary consciousness may be, upon what it depends. It must be granted that these subconscious systems give rise to many, if not all, of the effects of the complete system. We could personify them as readily as we do the experience of many other individuals. The only test of consciousness from the inside, however, is the personal test — that we are aware of it in introspection — and by definition this 'subconscious' does not belong to that class. So much of what contributes to our personal consciousness in very many important respects is not itself directly conscious that the difference may not be important. Of all of the myriad activities in the nervous system, only a few can be known at any moment, and, as has become apparent from the study of meaning and related processes, no one of these is consciousness of and for itself alone. It must always be grouped with a number of other activities, if consciousness is to result. Even then consciousness is limited, in most cases, to the things referred to or meant, rather than to the elements that are supposed to carry the meaning. Each group of nervous elements may by its activity contribute to the consciousness of the total, but the conditions of consciousness

must still be regarded as obscure. The most that can be said is that of the different systems that are found within the nervous system at any one time, the largest and most active is accompanied by consciousness. The others are either completely suppressed as in the case of the complexes of the subconscious or unconscious, or the minor systems contribute only in some slight degree to the total consciousness. Consciousness seems to be determined by or to accompany the activity of a system of nervous elements, connected by virtue of acting together in various systems of experiences. How many elements may be included in what corresponds to the centre of consciousness, and how far less central elements can play a part, no one can say. It can be asserted with assurance that even the most central features of consciousness correspond to the action of many neurones, show the effect of many experiences, and represent even more. Where the limits are to be drawn is not to be confidently stated.

Very little of the nervous action is really accompanied by consciousness, although very much of that activity has an effect upon consciousness. Much the same statement may be made of the functions of the individual as we deal with him in psychology and everyday life. We know that he remembers and recognizes, that he perceives objects and reaches conclusions, that he feels and chooses; we can even trace many of the conditions of these different operations, but he himself is conscious of little more than the outcome,—the causes are not revealed in consciousness. There is no occasion, then, to spend much time on the question whether some

of the hidden complexes of neural activities are accompanied by consciousness, when we know so little of the causes and effects of the highest, most fully revealed consciousness. A close analysis of self-consciousness gives as little reward. One has certain concepts that are represented by more or less definite imagery, but again the important factor is not the imagery but what the imagery represents. This is our notion of the whole as active, of the processes that direct our thoughts and acts, a continuous experience with the possibility of referring from any part to any other. All these are involved in the self idea, but are not all conscious at any time. The consciousness of self is seldom present and is of little importance when present, the self as the whole man active, as the unity and continuity of experience, is fundamental. It must be emphasized that this is not a single experience among the other experiences, it is not something of which we may become immediately conscious; on the contrary it is the man with all of his experiences and activities viewed as a whole.

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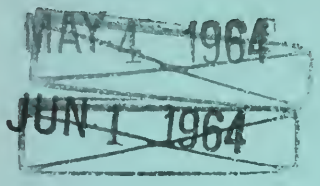

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